Šime MALENICA[1]
Ivo SENJANOVIĆ[2]
Quentin DERBANNE[1]
Nikola VLADIMIR[2]

On the EU FP7 Project: Tools for Ultra Large Container Ships - TULCS

O EU FP7 projektu: Alati za ultra velike kontejnerske brodove - TULCS

Dan je osvrt na povećani pomorski kontejnerski prijevoz i gradnju ultravelikih kontejnerskih brodova. Istaknuta je činjenica da su osnivanje i gradnja ultravelikih kontejnerskih brodova na margini postojećih pravila klasifikacijskih društava. Opisan je EU FP7 projekt *Alati za ultravelike kontejnerske brodove*, za razvoj integriranih projektnih postupaka i programske podrške na temelju numeričkih metoda, modelskih ispitivanja i mjerenja u naravi. Također, dan je pregled Međunarodne radionice o pruženju i podrhtavanju brodova, organizirane pri završetku osnovnih istraživanja u svrhu valorizacije i postavljanja smjernica za nastavak rada.

1 Introduction

The increase in the world trade has largely contributed to the explosion in sea traffic. In the last 25 years the total amount of marine trade has nearly doubled. In the same period container trade has grown approximately ten times faster, making the container fleet the fastest growing fleet at present. The first post-panamax container ship, with a capacity over 4500 TEU, entered service at the beginning of 1995. At the end of 2000 there were already more than 140 of post-panamax class ships sailing worldwide. In 2006, the *Emma Maersk* went into service: it is first of the new generation of ULCS, having a capacity to carry more than 11000 TEU. Furthermore, feasibility studies for containerships of 18000 TEU, the so called Malacca class, are already being examined. There are nowadays more than 16 million containers travelling worldwide, with an average increase of 10% every year. Other cargo transportation methods, such as break bulk, are being substituted with container transport additionally contributing to market growth.

With 80% to 90% of total EU imports and exports being transported by sea, the safety of seagoing ships is of the utmost concern to the EU nations and the European Commission. A market driven demand for ULCS, with lengths over 400 meters, raises the question of risks associated with their exploitation. Design and operation of such ships are challenging the existing rules of classification societies and/or the existing tools.

The structural design of ULCS is driven by the economies of scale of transporting large numbers of containers in one ship and the commercial pressures of reducing the total production cost and steel weight through optimisation. Due to this increase in size, the natural frequencies of the hull girder can fall within the range of wave load excitation forces. At the same time, due to operational requirements, the cruising speed of UCLS is relatively high (approximately 27 knots) increasing the encounter frequency significantly. In addition, commercial pressures for increased availability of the ship in severe weather conditions mean that increased operational envelopes are required by the operators. Several important issues affecting ULCS have been identified: nonlinear quasi-static hydrodynamic loading, springing, slamming, green water and whipping.

The current standard procedure for the determination of a ship's response in waves is split into two steps: hydrodynamic analysis of a ship (as a rigid body) using some of available linear or nonlinear hydrodynamic models; and quasi static structural analysis, using the pressures and accelerations, leading to the ship's structural response. This approach is physically incorrect, since ships in waves simultaneously experience both motions and deformations. However, most conventional ships are rigid enough so that their deformations remain relatively small. In such cases, the elastic modes' natural frequencies are significantly higher than wave excitation frequencies and standard procedures of separate hydrodynamic and structural analysis usually provide satisfactory results.

Due to their inherent properties, ULCS experience quite high elastic deformations. Their structural natural frequencies are low enough for sea waves to transfer enough energy for hull girder vibration excitation. In such cases, a complete study of the interaction between the hydrodynamic environment and the elastic structure needs to be undertaken. Besides this, a complete coupling of hydrodynamic and structural models should be applied in cases where impulsive loading, such as slamming, excites transient hull vibration - whipping.

Hydroelastic analysis enables more accurate check of design criteria:

1. hull girder ultimate strength: whipping due to slamming causes additional bending moments that can jeopardize primary hull strength,

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Adrese autora:

[1] *Bureau Veritas, Research Department,* 67/71 Boulevard du Château, 92200 Neuilly-sur-Seine, France,
e-mail: sime.malenica@bureauveritas.com

[2] *University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture,* I. Lučića 5, 10000 Zagreb, Croatia,
e-mail: ivo.senjanovic@fsb.hr

2. fatigue of structural details: by neglecting the effect of springing, accumulated damage could be significantly underestimated.

There are relatively efficient numerical models for global hydroelastic ship response analysis in the vertical plane, which is relevant for most ship types. No similar method is developed for container ships where the relevant natural frequencies belong to the coupled horizontal and torsional vibrations. Therefore, there is a strong need for a reliable coupled model for hydroelastic response calculations of ULCS.

The recent RINA conferences on design and operation of the container ships [1, 2] clearly illustrate the actual situation and difficulties related to the design and operation of the ULCS. Even if there is not much experience in the operation of ULCS, the physical understanding of different phenomena related to ULCS indicates that some serious risks might influence ULCS design. It is clear that the hydroelastic phenomena, such as springing and whipping, make significant contributions to both extreme and fatigue structural design characteristics, as probably experienced by the *MSC Napoli* in early 2007 (see already mentioned MAIB report [3]). However, the methods for calculating these contributions as well as the methodology to include them into the design/verification procedure in a rational way are still not implemented. This is due not only to the imperfection of the existing tools but also to the unclear definition of the representative design operating conditions.

As far as the ship operation is concerned and even if, up to now container carriers have very good safety record with respect to structural integrity, the losses related to container transport are significant. The number of containers lost overboard is estimated to be between 2,000 and 10,000 containers every year. The average value per TEU is estimated by insurance companies to be close to USD 44,000, resulting in a total loss of up to USD 440 million every year. It is also immediately clear that loosing just one Malacca class ship is approximately equal to USD 1 billion loss.

The most probable reasons for these current losses, and the possible future losses, are the specific ship design and the very demanding operating conditions, which, as previously stated, can lead to a particular behaviour in waves. In addition to the "normal" ship accelerations, due to the classical linear seakeeping behaviour there are strong indications for the increase of the accelerations due to slamming induced vibrations (whipping).

2 Description of the TULCS project

The above state-of-the-art gave incentive to further investigation of ship hydroelasticity. Due to complexity of this challenging task, the project TULCS has been created by 14 institutions and companies (listed in Table 1) within the EU FP7 call with engagement shown in Figure 1 [4]. The project will last 3 years, and its final goal is to deliver clearly validated tools and guidelines, capable of analyzing all hydro-structure interaction problems relevant for efficient and safe design of ULCS.

Figure 1. **Partners of the TULCS project**
Slika 1. **Partneri u projektu TULCS**

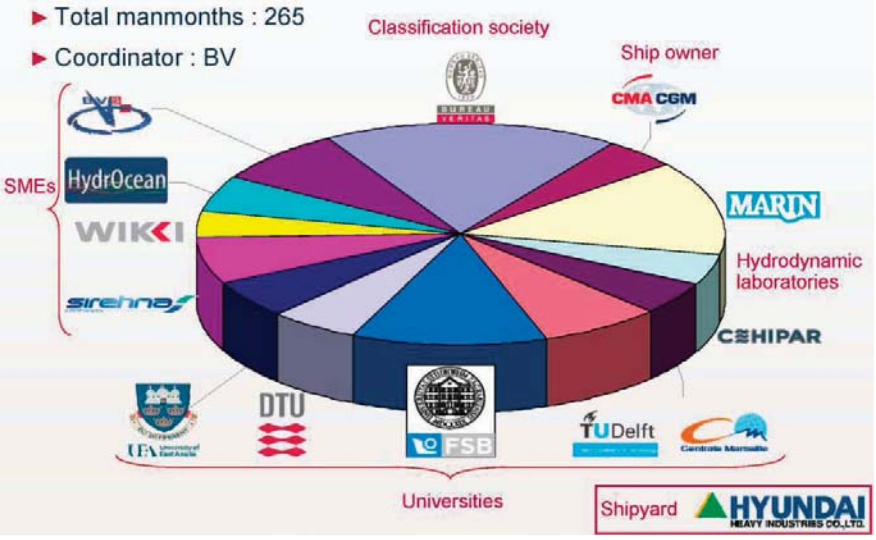


Table 1 **Project partners**
Tablica 1 **Partneri projekta**

No	Name	Short Name	Country
1	Bureau Veritas (coordinator)	BV	France
2	Marin	MARIN	Netherlands
3	Compagnie Maritime d'Affrètement – Compagnie Générale Maritime	CMA-CGM	France
4	Canal de Experiencias Hidrodinamicas	CEHIPAR	Spain
5	Ecole Centrale Marseille	ECM	France
6	Technical University Delft	TUD	Netherlands
7	University of Zagreb	UZ	Croatia
8	Technical University of Denmark	DTU	Denmark
9	University of East Anglia	UEA	United Kingdom
10	SIREHNA	SIREHNA	France
11	WIKKI	WIKKI	United Kingdom
12	HYDROCEAN	HO	France
13	Brze Vise Bolje	BVB	Croatia
14	Hyunday Heavy Industries (joint partner)	HHI	South Korea

Table 2 **Work packages**
Tablica 2 **Radni paketi**

WP	TITLE	Package leader
1	Project management	BV
2	End-user requirements	CMA-CGM
3	Global quasi static wave loading and response	BV
4	Global hydroelastic loading and response	UZ
5	Local hydrodynamic loading and response	MARIN
6	Model tests	CEHIPAR
7	Full scale measurements	MARIN
8	Overall technical coordination and integration	DTU
9	Demonstration, dissemination and exploitation	UZ

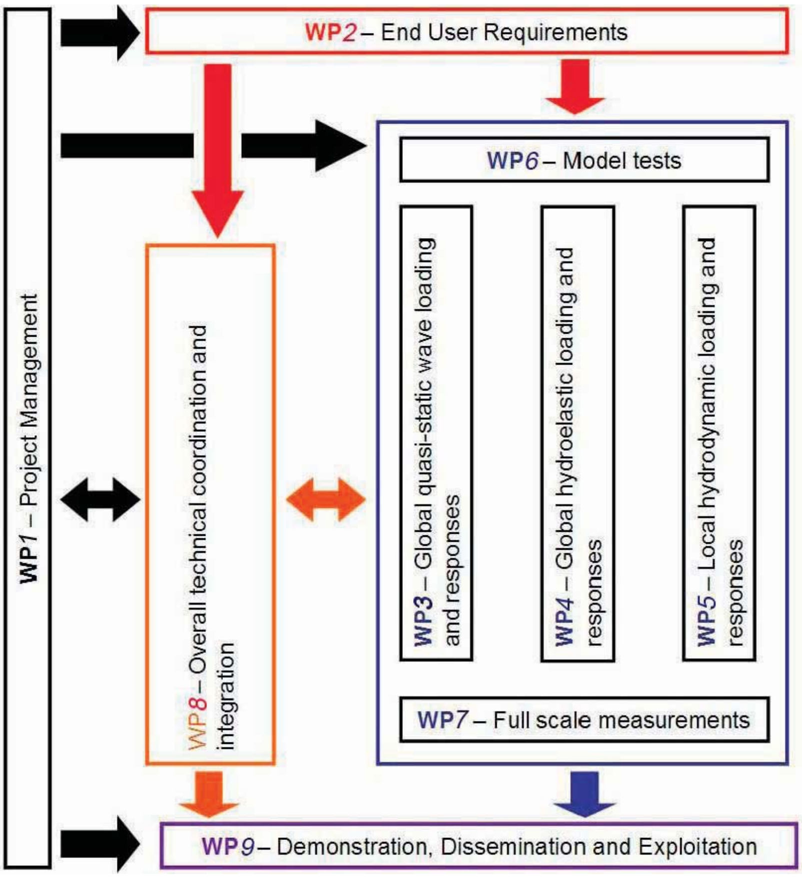


Figure 2 **Overall project organization**
Slika 2 **Prikaz organizacije projekta**

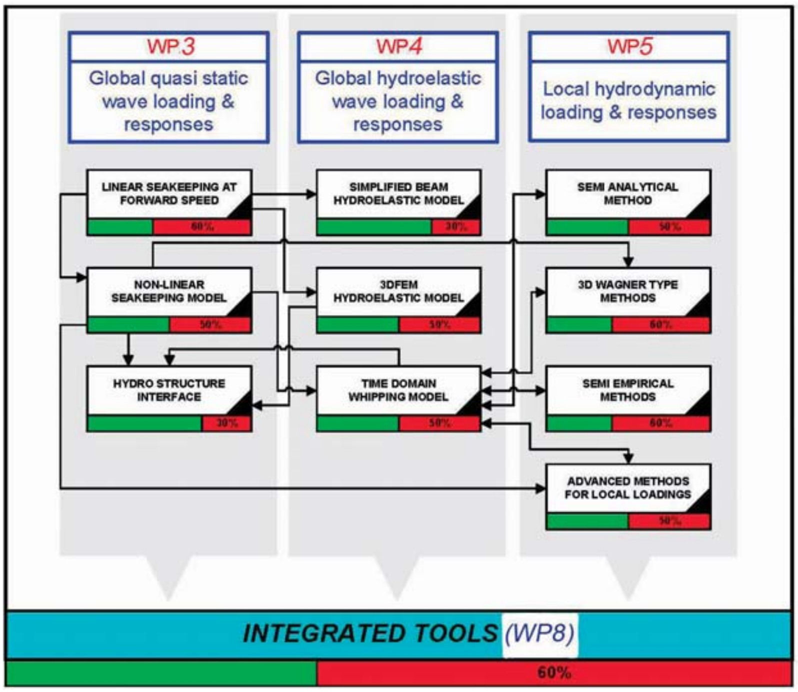


Figure 3 **Different tools and their degree of development (remaining part in red)**
Slika 3 **Različiti alati i njihov stupanj razvoja (preostali dio u crvenom)**

The project consists of 9 inter-dependent work packages carrying the technical work, Table 2. Its organization is shown in Figure 2. The consistency of the technical activities, towards the achievement of the main objective, is ensured by starting the project with the specification of the end-user requirements, which is further used to specify the details of the technical developments. Three main physical problems are identified and for each of them a dedicated work package is created, WP3, 4 and 5, Figure 3. The integrated design tools are combination of the numerical developments, model tests and full scale measurements, WP 6 and 7, respectively. The main descriptions of the 9 work packages are presented hereafter.

WP1 Project management

This work package will manage and organise the TULCS project so that the objectives of the different work packages will be achieved. It will ensure the administrative management of the project with technical and financial reporting to the European Commission, collection and transmission to the EC of cost statements and audits, organisation of periodic progress meetings.

WP2 End-user requirements

This WP will produce the clear end-user requirements for the final deliverables. This concerns both design and operational issues. At the same time the requirements for the integration of different technical work will be established.

WP3 to WP5 are the module adaptation work packages. Each of them concerns the particular technical issue which was identified at the beginning of the project. Each of these work packages will have a similar structure:

1. Benchmark and selection of the most appropriate numerical tools and methods
2. Improvement/adaptation of the selected simplified tools
3. Improvement/adaptation of the selected sophisticated tools
4. Validation with respect to experiments and full scale measurements
5. Software documentation
6. Software integration into overall design tools.

As mentioned several times, the different software developments will always include both simplified and sophisticated tools. This is a very important point, since different types of application are targeted. Indeed, some applications (for example, initial design stage and long term statistics of structural loads) require very fast software and can accept less accurate tools. While the final design stage applications require very accurate tools but can accept larger CPU time.

On the other hand, special care will be given to the validation of different pieces of software. That is why two classes of experiments will always be performed:

- Simplified tests for detailed validation of different parts of the developments
- Sophisticated model test for fully integrated modules.

At the same time the full scale measurements will also be available giving the final indication of the utility of different software.

WP3 Global quasi static wave loading and responses

Within this work package a fundamental technical problem which represents the basis for all other developments, will be considered. It is a problem of seakeeping at forward speed. It is fair to say that this problem is still an open problem and no fully satisfactory numerical model exists up to now. Based on the experience of different project partners, the development of the pure CFD RANSE type of models will not be covered, but the so called potential flow models will be. However, the CFD based numerical code will be used on a few representative examples in order to assess the degree of their applicability for these types of applications.

In particular, two types of the approaches will be mixed, namely Rankine and Kelvin type models. Indeed, both of them have several advantages and disadvantages, and the idea is to combine them by keeping only their advantages. Another good point of this approach is relatively easy inclusion of nonlinear effects such as interaction of the steady and unsteady flows and the Froude Krylov type of approximations.

This WP is a critical part of the project and the developments which are done here, will serve for coupling with all other modules (for example, springing, whipping, slamming and green water).

WP4 Global hydroelastic wave loading and responses

The aim of this WP is to produce efficient fully coupled hydro-structural models for evaluation of the global hydroelastic ULCS responses. These models have two relatively independent parts: hydro and structure, which need to be efficiently coupled together. In principle the structural models are rather reliable as compared to hydrodynamic models and the main problem would be the coupling, provided the hydrodynamic seakeeping model from WP3 is efficiently done. Indeed, the important experience in hydro structure coupling already exists and should only be adapted to the present needs. Both simple beam structural models and full 3DFEM models will be considered.

WP5 Local hydrodynamic loading and responses

Two main types of local loadings which will be considered in this WP are slamming and green water. These problems represent huge numerical difficulties on their own i.e. independently of the seakeeping part to which they need to be coupled. Important experience exists, but there is still a long way to go before obtaining the fully accurate method for slamming and green water. The idea in this WP is to improve existing simplified tools by enriching them with some complex CFD calculations. At the end of the developments they need to be properly coupled with the seakeeping and the structural parts in order to asses their influence on the global ship responses. On the other hand, special attention will be given to the local hydro-structure interactions during slamming and green water events. Indeed, these effects might be responsible for some local damages in the bow, stern and deck area.

WP6 Model tests

This work package will coordinate and perform the different measurement campaigns which are planned within the project. This WP will allow optimising the test plans by first analysing the test requirements from the technical work packages WPs 3 – 5, which are likely to overlap, so that the same experimental campaigns are likely to cover different tool developments. Both simplified and more sophisticated test configurations will be performed because of the sharpness of some of the phenomena to be modelled, which requires very detailed validation of different assumptions.

WP7 Full scale measurements

In this work package the main investigations will cover the full scale measurements on a 9200 TEU Container ship of CMA-CGM. The already existing instrumentation for acceleration and global strain measurements will be supplemented by the efficient sea state measurements and local strain measurements in the bow and stern area. These measurements will be used for final validation of the developed software.

WP8 Overall technical coordination and integration

This work package will ensure:

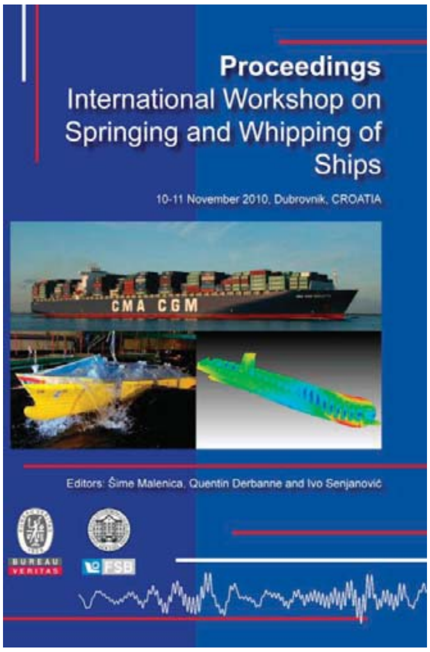
- Overall technical coordination of different numerical developments and measurements
- Integration of the different tools into a common platform
- Integration of the design procedures into a common platform.

WP9 Demonstration, dissemination and exploitation

The activities in this work package are oriented towards the future exploitation of the design tools, with:

- Demonstration of the use of the tools for one existing ship design and comparisons with the actual procedures
- Preparation of documents such as manuals and guidelines, identification of remaining steps after the end of the project for commercialisation of the tools.
- Continuous dissemination of the project progress and results to the marine stakeholders, general public and wider scientific community.

3 Workshop of the TULCS project



Proceedings
International Workshop on
Springing and Whipping of
Ships
10-11 November 2010, Dubrovnik, CROATIA

Editors: Šime Malenica, Quentin Derbanne and Ivo Senjanović

Figure 4 **The front page of the Workshop Proceedings**
Slika 4 **Naslovna stranica Zbornika radionice**

In the middle of the TULCS project the International Workshop on Springing and Whipping of Ships was organized jointly by the *University of Zagreb* and *Bureau Veritas*, in Dubrovnik on 10th and 11th November 2010. The Workshop took place at the *Center for Advanced Academic Studies* of the *University of Zagreb* (*CAAS*). Its purpose was to exchange the ideas and experience related to the problems of ULCS within the informal and constructive discussions.

The workshop was attended by representatives from classification societies, universities, research institutes, shipbuilders, ship-owners and ship captains, i.e. all relevant subjects that are interested in the improvements of ship design tools. The Proceedings reflect the general opinion that only the combination of numerical tools, model tests and full scale measurements could give rational methodology for ULCS design [5]. However, real life operation of ULCS from the point of view of a master should be taken into account. In spite of modern technology assistance, the role of the master is still crucial for the crew, ship and cargo safety. From the view point of a ULCS captain, the avoiding of the heavy seas is still most important for ship safe navigation.

The Workshop confirms the importance of inclusion of hydroelastic issues in overall ship design procedure. In that sense it is interesting that shipbuilders (as for example *HHI*) take into account springing induced fatigue in the process of hatch corners design. Although there is no complete solution either for springing and whipping, it seems that slamming (bottom or bow flare) induced whipping and related increase in bending moment as well as fatigue damage accumulation, represent the most complicated problems connected to design of ULCS. It is obvious that the remaining part of the project TULCS will significantly contribute to solving these challenging tasks.

Totally 28 lectures were presented by the Project members and the invited experts, as listed in the Appendix. Since the Workshop was quite informal, the Proceedings do not include classical papers but a short abstract of each presentation, the presentations and discussions, i.e. questions and authors' replies. The abstract of the introductory lecture (Š. Malenica), invited lectures (O.M. Faltinsen, I. Šikić) and some lectures related to the structural design, structural modelling and full scale measurements (B.K. Choi, I. Senjanović, C. Fresser) are enclosed in Appendix.

4 Conclusion

The present paper is a dissemination of the TULCS Project in the middle of the investigation, and the workshop is a milestone to evaluate the obtained results, discuss them among the Project participants and the other experts, and direct further research. The success of this task can be seen in the Workshop Proceedings. All numerical methods and simulations will be checked by correlation of the model tests and full scale measurements, which will be shown in the deliverable reports. At the end of the Project the closing conference will be organized for presentation and evaluation of the achieved results before their application for ship design.

Acknowledgements

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[5] Proceedings of the International Workshop on Springing and Whipping of Ships, Eds.: Š. Malenica, Q. Derbanne, I. Senjanović, BV, UZ, Dubrovnik, 2010., available at: www.fsb.hr/tulcs

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Appendix – List of the Workshop lectures and selected abstracts

1. **Hydro structure issues in the design of ULCS**
   Šime Malenica, Bureau Veritas, France
2. **Presentation of TULCS Project**
   Quentin Derbanne, Bureau Veritas, France
3. **Hydrodynamic aspects of springing, slamming and whipping**
   Odd. M. Faltinsen, Norvegian University of Science & Technology NTNU, Norway
4. **Operation of ULCS - Real life**
   Igor Šikić, CMA-CGM, France

5. **Structural Design of ULCS by Combining the Rule and Direct Calculation Procedure**
Byung Ki Choi, Hyundai Heavy Industries, South Korea
6. **Influence of environmental and operational uncertainties on design wave loads of containerships**
Joško Parunov, University of Zagreb, Croatia
7. **Some aspects of 3D Wagner model of slamming**
Yves Marie Scolan, Ecole Centrale de Marseille, France
8. **An Approximate Slamming Prediction Method**
Geert Kapsenberg, Maritime Research Institute, The Netherlands
9. **Local structural response by slamming**
Johan Tuitman, TNO Center for Maritime and Mechanical Structures, Netherlands
10. **Fluid-Structure Interaction Using Free Surface RANS- and Finite Element Methods**
Ould el Moctar, Germanischer Lloyds, Germany
11. **Impulse loading and hydroelasticity with SPH method**
Olivia Thilleul, Hydrocean, France
12. **Slamming calculations using CFD**
Hrvoje Jasak, WIKKI, United Kingdom
13. **CFD predictions of 3D-slamming loads**
Sopheak Seng, Technical University of Denmark, (DTU)
14. **Hydroelastic Springing Analysis of Large Ships with the Effect of Forward Speed and Instantaneous Wetted Surface**
Yousheng Wu, China Scientific Ship Research Center, China
15. **Forward speed effects on ship motions**
Tim Bunnik, MARIN, Netherlands
16. **A coupled Rankine – Green function method applied to the forward-speed seakeeping problem**
Igor Ten, Bureau Veritas, France
17. **Advanced beam model for hydroelastic analysis of container ships**
Ivo Senjanović, University of Zagreb, Croatia
18. **Numerical analysis of ship springing by using WISH-FLEX**
Yonghwan Kim, Seoul National University, South Korea
19. **Simulation of non-linear wave induced responses using the Monte Carlo method with artificially increased significant wave height**
Jørgen Juncher Jensen, Technical University of Denmark – DTU, Denmark
20. **Hydroelastic prediction and model test of springing and whipping responses of a 500,000 DWT Ultra Large Ore Carrier**
Jia-Jun Hu, China Scientific Ship Research Center, China
21. **Comments on rigid and elastic segmented model tests**
Jean Marc Rousset, Ecole Centrale de Nantes, France
22. **Experimental investigation of the correlation of slamming and whipping phenomena**
Daniele Dessi, Insean, Italy
23. **The effect of heading on springing/whipping induced fatigue damage from model scale and full scale measurements – for container vessels**
Gaute Storhaug, DNV, Norway
24. **Onboard monitoring of fatigue damage rates – Decision support and sea state estimation**
Ulrik Dam Nielsen, Technical University of Denmark – DTU, Denmark
25. **Sea state measurements – Instrumentation on board CMA-CGM Rigoletto**
Camille Fresser & Denis Martigny, Sirehna
26. **Fatigue assessment on a Very Large Container Ship**
Mathieu Renaud, CMA-CGM, France
27. **In service global hull deformations and section loads for a large containership**
Jos Koning, MARIN, Netherlands
28. **Analysis of full scale measurement data of Large Container Ships on the effect of the springing response**
Ryuji Miyake, ClassNK, Japan

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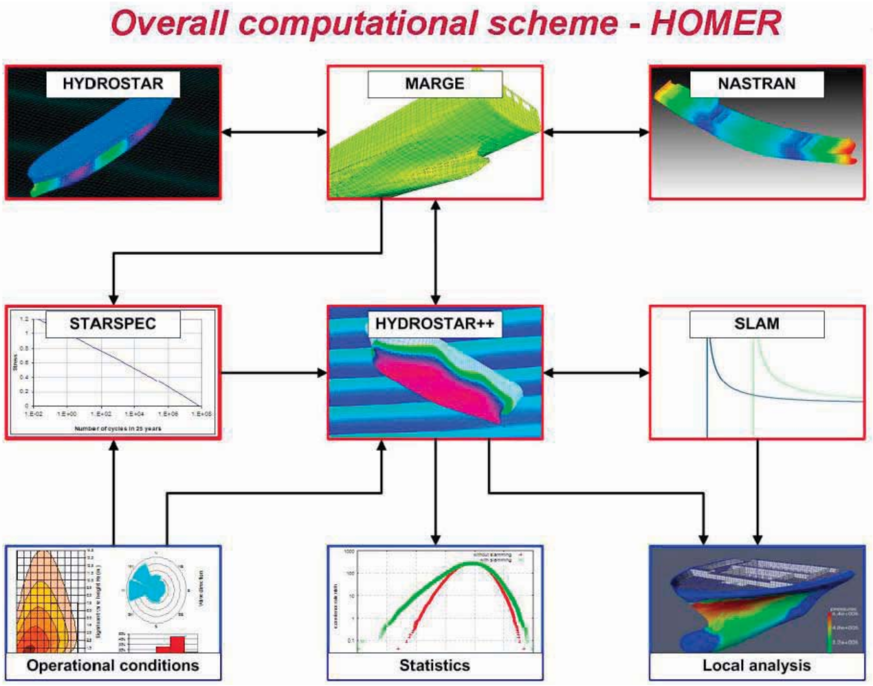
Hydro structure aspects of ULCS design

Šime Malenica, Bureau Veritas, France

An overview of the different hydro-structural issues within the context of the design of the Ultra Large Container Ships is presented, Figure 5. The accent is put on the direct calculation tools and on the overall methodology. The specificity of the ULCS, compared to the more classical ship designs, is that they are more

Figure 5 **Overall computational scheme**
Slika 5 **Računalna shema**



likely to experience the hydro-elastic type of structural response, i.e. springing and whipping. There are several reasons for that:

- increase of the flexibility due to their large dimensions (Lpp close to 400 m) and large hatch openings, which lead to the lower structural natural frequencies
- very large operational speed (> 25 knots)
- large bow flare (risk of slamming increased).

Indeed all these facts increase the risk of the hydroelastic wave induced resonance in usual sea states (springing) and, at the same time, the risk of slamming is increased leading to higher probability of the transient hydroelastic response (whipping). It is fair to say that the modelling of springing and whipping is still a challenge and that there is no fully satisfactory numerical tool able to deal with these issues in the general case. At the same time the other available tools such as model tests and full scale measurements have their own drawbacks (high cost, limited number of the covered cases, representativity of the beam model…) so that no definite opinion can be made on this subject for the moment. Anyhow, it seems to be clear that more attention should be given to these issues in the near future, because there is clear evidence (numerical, model tests & full scale) that these hydroelastic types of structural responses exist and that their effects can be quite important both for fatigue and extreme response issues. In addition, the analysis of some recent accidents indicates that whipping and springing are likely to be the reason, at least partial, for the structural failure. On the other hand, it is important to note that, even without the inclusion of the hydroelastic effects, the classical quasi static hydro-structure interactions are also not perfectly mastered and their inclusion into the design procedures still appears not to be fully satisfactory. This is true both for the imperfections of the deterministic hydro-structure calculation models and (even more) for the overall methodology for their inclusion (representative sea states, operational conditions, probability levels…).

In this presentation a special attention is given to some non trivial technical details of the deterministic modelling of the different hydro-structural aspects:

- balancing of the linear and non linear quasi static structural 3D FE model
- hydroelastic coupling and modal approach
- separation of the quasi static and dynamic responses in order to improve the convergence
- inclusion of slamming loads into the whipping model
- top-down methodology for fatigue analysis of the structural details
- statistical post processing.

The main intention was to point out the difficult points and identify the possibilities for improvements of the existing tools and methods. In any case, one thing seems to be clear: the evolution of the existing design tools and methods will necessarily go towards the direct calculation procedures regardless of the modelling complexities. At the present stage of the developments, it seems that only the combination of the 3 available methods of analysis (numerical tools, model tests, and full scale measurements) will be able to give some rational methodology for the inclusion of these effects in ship design. However, there is a still long way to go before fully succeeding in achieving that.

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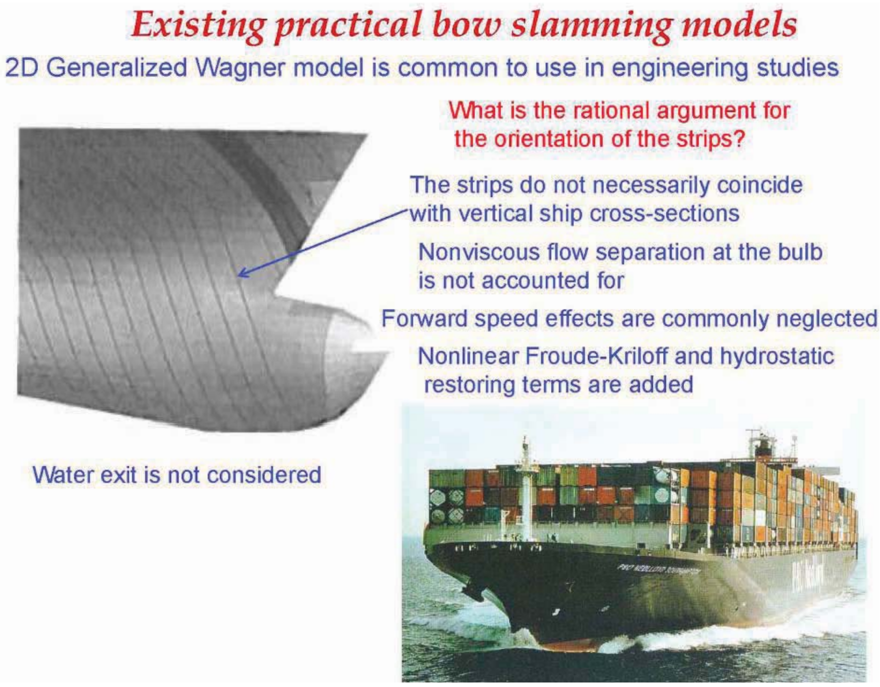
Hydrodynamic aspects of springing, slamming and whipping

Odd. M. Faltinsen, Norvegian University of Science & Technology NTNU, Norway

Focus was on discussing simplified methods instead of CFD methods. Weakly nonlinear methods are relevant for linear and second order springing in moderate sea conditions with small rigid-body motions. Damping remains an uncertainty and needs more attention. Hydrodynamic damping sources are flow separation at the bilge-keels, hull-lift damping and wave radiation from shallow hull parts. Proper consideration of the steady wave field seems important. When it comes to linear methods, numerical problems may occur when properly accounting for all wave systems. It was questioned if it is necessary to account for all the wave system. The so-called mj-terms in the body-boundary conditions cause problems for sharp corners and high-curvature surfaces. Using a body-fixed coordinate system in describing the flow will avoid the problem. A strip theory cannot properly describe linear excitation of springing. It was illustrated that the second-order po-

Figure 6 **Existing practical bow slamming models**
Slika 6 **Postojeći praktični modeli udaranja pramca o valove**


Existing practical bow slamming models

2D Generalized Wagner model is common to use in engineering studies

What is the rational argument for the orientation of the strips?

The strips do not necessarily coincide with vertical ship cross-sections

Nonviscous flow separation at the bulb is not accounted for

Forward speed effects are commonly neglected

Nonlinear Froude-Kriloff and hydrostatic restoring terms are added

Water exit is not considered

tential has dominant influence on the second-order vertical force on a Wigley hull in regular head sea waves at zero speed. A perturbation method will have problems in describing higher order effects in frequency domains with large rigid-body motions due to non-vertical ship surface at the water surface. The latter effect is relevant for third and higher-order springing excitations. It is in any case impractical to account theoretically for higher than second order effects.

Whipping is excited by bow-flare slamming and possibly by water impact on a nearly flat overhang at the transom of a container vessel. It was illustrated by model tests with drop tests of a ship-like body, that three-dimensional flow effects are important at the ship ends. A three-dimensional generalized Wagner method was showing good agreement with experiments, Figure 6. It is common in engineering practice to use a two-dimensional generalized Wagner method in describing bow-flare slamming. However, by examining some bow shapes of container vessels it is evident that 3D flow effects must matter. Features that must also be accounted for is the forward ship speed as well as the fact that the dynamic free-surface condition is not necessarily zero velocity potential. The latter condition is relevant for a slamming condition starting with bow emergence. It is therefore not obvious how to incorporate the 3D generalized Wagner method to improve whipping excitation due to the bow flare. It was suggested instead to incorporate the effect directly in combination with a linear 3D hydrodynamic model by associating nonlinear loads with nonlinear Froude-Kriloff and restoring loads as well as terms involving the rate of change of the wetted surface based on linear theory. However, there is no documentation that such a pragmatic model works. The slamming on a nearly flat overhang at the transom has resemblance to the wet deck slamming problem. The difference is in the more complicated inflow condition. What we can learn from earlier experimental and theoretical studies of the global effect of wet deck slamming in head sea waves is: Both the water entry and water exit phases are important. The wet deck hydrodynamic loads in a global analysis can be adequately described by von Karman's method in combination with nonlinear hydrostatic and Froude-Kriloff loads. Good agreement between experiments and theory was documented for wet deck hydrodynamic forces as well as global vertical shear forces and bending moments.

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Operation of ULCS - Real life

Igor Šikić, CMA-CGM, France

Figure 7 **Ship in real conditions**
Slika 7 **Brod u realnim uvjetima**

In this presentation the real life operation of ULCS (Ultra Large Container Ships) is presented from the point of view of a master, Figure 7. Ship handling has always been placed firmly in hands of the ships master. What of course makes the task of the ship handler so challenging is that many elements are not under his control but still have to be catered for, such as weather, current, wind effects, respective underkeel clearance, geographic obstructions with narrows, etc. The problems during exploitation of ULCS in everyday work are addressed, dealing with voyage management, crewing, and compliance, as well as giving navigational decision support for ships in operation. The difficulties are mainly related to port handling and sailing at heavy seas. The integrated onboard system that provides ship's officers with decision-making support is presented combining advanced computations with seaway measurements and wave forecasts. It supports masters to navigate more safely in extreme weather conditions – for example by avoiding parametric rolling and slamming, therefore the risk of damage to the ship, cargo and environment as well as injuries to the crew are reduced. On today's modern vessels computerized engine can automatically reduce speed due to the heavy weather according to specific extracted data from operational systems for tailor made decision support. However, in spite of all assistance of modern technology the role of ship master on ULCS is even more important. Each ship is provided with the ISM Check list for bad weather – engine and deck. Even so, the particular situations when captain decides to slow down or changes the heading are typically individual actions, where there are no specific rules. However, the most usual reasons why master changes the ship heading or speed are to avoid slamming, excessive rolling and other situation which, from his point of view, can jeopardize people, ship or cargo. The strong wind loads also represents the serious problem on ULCS especially in port handling. Vibrations in shallow waters are emphasized. The problem with the cargo distribution before leaving the port and how this condition is controlled is presented as well.

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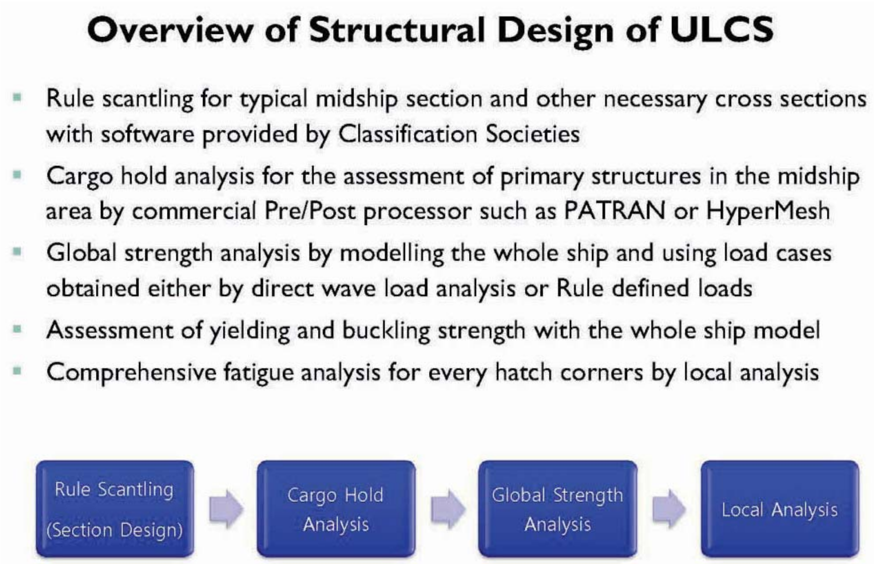
Structural Design of ULCS by Combining the Rule and Direct Calculation Procedure

Byung Ki Choi, Hyundai Heavy Industries, South Korea

In case of ULCS, the effect of springing response is expected to have much effect on the fatigue strength due to big size of ship length and high operating speed. *Hyundai Heavy Industries (HHI)* has delivered a 13,100 TEU class containership to the ship owner recently and



Overview of Structural Design of ULCS

- Rule scantling for typical midship section and other necessary cross sections with software provided by Classification Societies
- Cargo hold analysis for the assessment of primary structures in the midship area by commercial Pre/Post processor such as PATRAN or HyperMesh
- Global strength analysis by modelling the whole ship and using load cases obtained either by direct wave load analysis or Rule defined loads
- Assessment of yielding and buckling strength with the whole ship model
- Comprehensive fatigue analysis for every hatch corners by local analysis

Rule Scantling (Section Design) → Cargo Hold Analysis → Global Strength Analysis → Local Analysis

Figure 8 **Overview of structural design of ULCS**
Slika 8 **Pregled osnivanja konstrukcije ultravelikih kontejnerskih brodova**

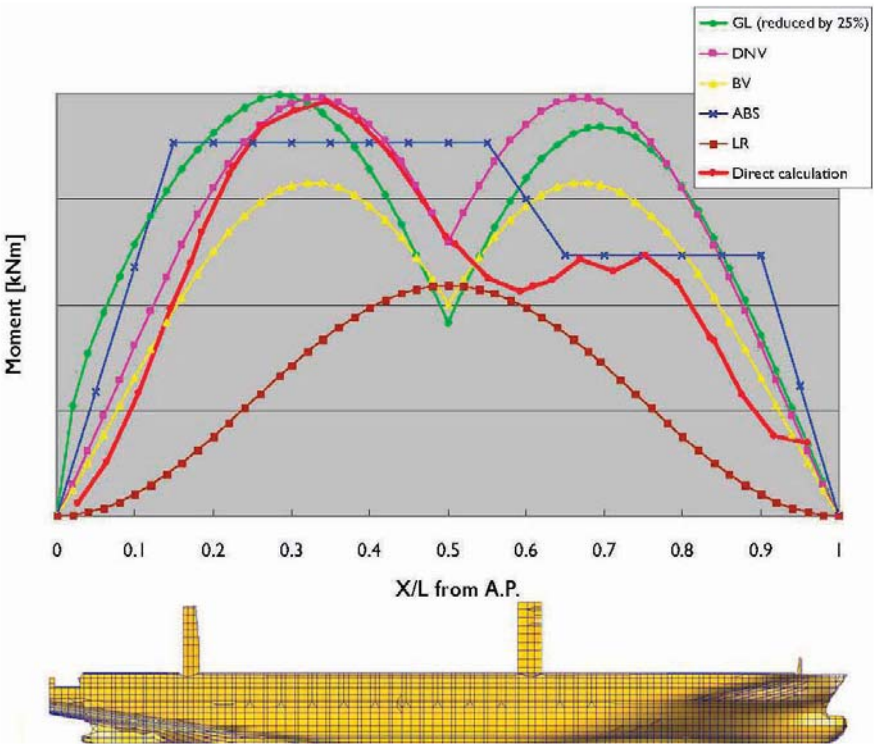


Figure 9 **Distribution of torsional moment**
Slika 9 **Raspodjela torzijskog momenta**

a vast amount of numerical calculations have been carried out to look for a reasonable solution for fatigue design of hatch and bench corners with consideration of springing response, Figure 8.

Rule-based fatigue analysis was carried out to investigate the safety margin, which is used as the basis for additional reinforcement, Figure 9. New numerical code was adopted to obtain the stress RAO for the specific hatch corner, taking into account the high frequency responses of hull girder loading such as TM and HBM as well as VBM.

The decrease of fatigue life due to springing response was calculated quantitatively and the additional reinforcement was done.

Some further studies are needed to enhance the numerical accuracy of springing response and whipping effect is also to be considered to increase the structural redundancy in the severe sea state.

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Advanced beam model for hydroelastic analysis of container ships

Ivo Senjanović, University of Zagreb, Croatia

The combination of beam structural model and 3D hydrodynamic model is a rational choice for hydroelastic analysis of large container ships in early design stage since the detailed technical documentation is not available yet. The main problem of container ship response is coupling between horizontal bending and torsion. In order to increase the accuracy of the hydroelastic analysis, an advanced beam structural model, which takes shear influence both on bending and torsion into account [1], is developed. Normal and shear stress flows, and stiffness moduli, i.e. shear area, torsional modulus, shear inertia modulus, and warping modulus [2] are determined by the program STIFF based on strip element method.

Several formulations of the modal restoring stiffness, from simple to more complex ones, are known (Price, Newman, Malenica, Molin, etc.). Table 1 shows three of them that are often used nowadays. Huang & Riggs formulation, Eq. (1), started from geometric stiffness with additional hydrostatic terms obtained by linearization of the governing equations. It is generally valid for ship and offshore structure. By applying zero strain constraint, Eq. (1) is reduced to Eq. (2) valid only for rigid body modes. Exactly the same set of formulas, Eq. (2), is obtained by a direct derivation in which rigid body and elastic modes are treated in the same manner. It is shown that Eq. (2) is valid for an elastic body with low initial stresses. Eq. (3) is obtained by comprising Eq. (2) with geometric stiffness in order to achieve general formulation. Hence, two additional terms are obtained comparing to Eq. (1), and their contribution has to be investigated, [3].

Program package HYELACS, comprised of program DYANA for beam structural model natural modes determination and HYDROSTAR for 3D hydrodynamic response, has been developed for the purpose of hydroelastic response (springing in the frequency domain and transient in the time domain) calculation. Numerical procedure is checked by correlation analysis of the calculated and measured results for a segmented barge, which is recently used as a benchmark for such analyses.

Modelling of ship structure by a beam is illustrated in case of a 7800 TEU container ship. Two main problems arise, i.e. contribution of transverse bulkheads to torsional hull stiffness, and behaviour of relatively short engine room structure. In the former case, the equivalent torsional modulus is determined by increasing ordinary (St. Venant) value, depending on the strain energy ratio of a bulkhead and corresponding hull portion [4]. A similar energy approach is used for determining equivalent torsional modulus of relatively short engine room structure. It is assumed that a short closed structure behaves as an open one with the contribution of decks [5]. In addition, distortion of engine room structure, caused by different shear stress distribution at the boundary (i.e. at transverse bulkhead, at the transition from closed engine room to open hull side), is analyzed. The bulkhead distortion is used as the boundary condition for bending of the deck girder, treated as a beam on elastic supports. Hence, the total normal stress in deck girder consists of two parts: one due to restrained warping and another due to bending imposed by the distortion. Determination of stress concentration is a prerogative for fatigue analysis. For the purpose of checking the advanced beam theory in case of a prismatic pontoon with a ship-like cross-section, 3D FEM analysis is performed. It turns out that, due to shear influence on torsion, the shear centre does not coincide with the twist centre.

Dry natural vibrations analysis of the advanced beam model and 3D FEM model of the complete ship shows very good agreement, Figure 10. Hydroelastic response emphasizes peak values of transfer functions due to resonances at the encounter frequency. Transfer function of sectional forces has to converge to zero value as the encounter frequency approaches zero, as in the case of rigid body analysis. This is achieved by applying the consistent restoring stiffness.

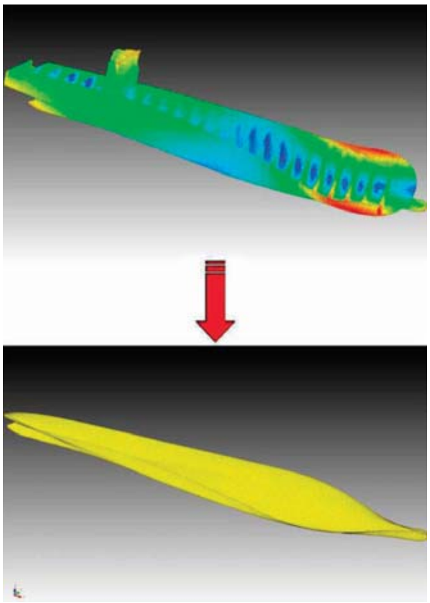

Figure 10 **Transfer of modal displacements from structural to hydrodynamic mesh**

Slika 10 **Prijenos modalnih pomaka sa strukturne na hidrodinamičku mrežu**

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Sea state measurements instrumentation on board the *CMA-CGM Rigoletto*

Camille Fresser & Denis Martigny, Sirehna

According to the seventh work package of TULCS European project, Full Scale Measurements are performed on board an ultra large container ship, so as to provide data for the next step of the study: Integrated Design Tools.

Since 2006, the *MARIN* institute has been working with the *CMA-CGM* shipping company for the integration of strength sensors and accelerometers along the hull and structure of the chosen ultra large container ship *CMA-CGM Rigoletto*, a 9415 TEU capacity vessel built in Korea by *Hyundai Heavy Industries*. Part of the “French-Asia Line 3” fleet, the *Rigoletto* runs a regular service between the North Sea and the Sea of China (10 weeks, 15 destinations). In August 2010, *Sirehna* company proceeded to the integration and commissioning of experimental devices designed to assess the sea state encountered by the vessel during its journey.

The sea state measurement system installed by *Sirehna* is composed of two complementary and new devices: a Wave Monitoring System (WaMoS) lighting the surroundings from the top of the wheelhouse, and two WaveGuide Systems (WGS) looking down the bow, Figure 11. All the onboard measurements for the TULCS project are concentrated and saved on a single *MARIN* computer through the ship’s Ethernet network.

Designed by OceanWaveS, the WaMoS technology is based on analysis of raw radar images of the surrounding sea. This system need the installation of dedicated navigational X-band radar, operated in short range and with no filter applied on the sea clutter. A new radar antenna has been added to the upper bridge of the *Rigoletto*, and plugged to a control and monitoring unit inside the wheelhouse. Every 2 minutes, the WaMoS automatically broadcasts statistical sea state data on the network.

On both sides of the wave-breaker, *Sirehna* also installed two directional X-band radars above the sea surface, so as to record elevation differences and determine the height and the period of waves encountered forward the vessel. The port

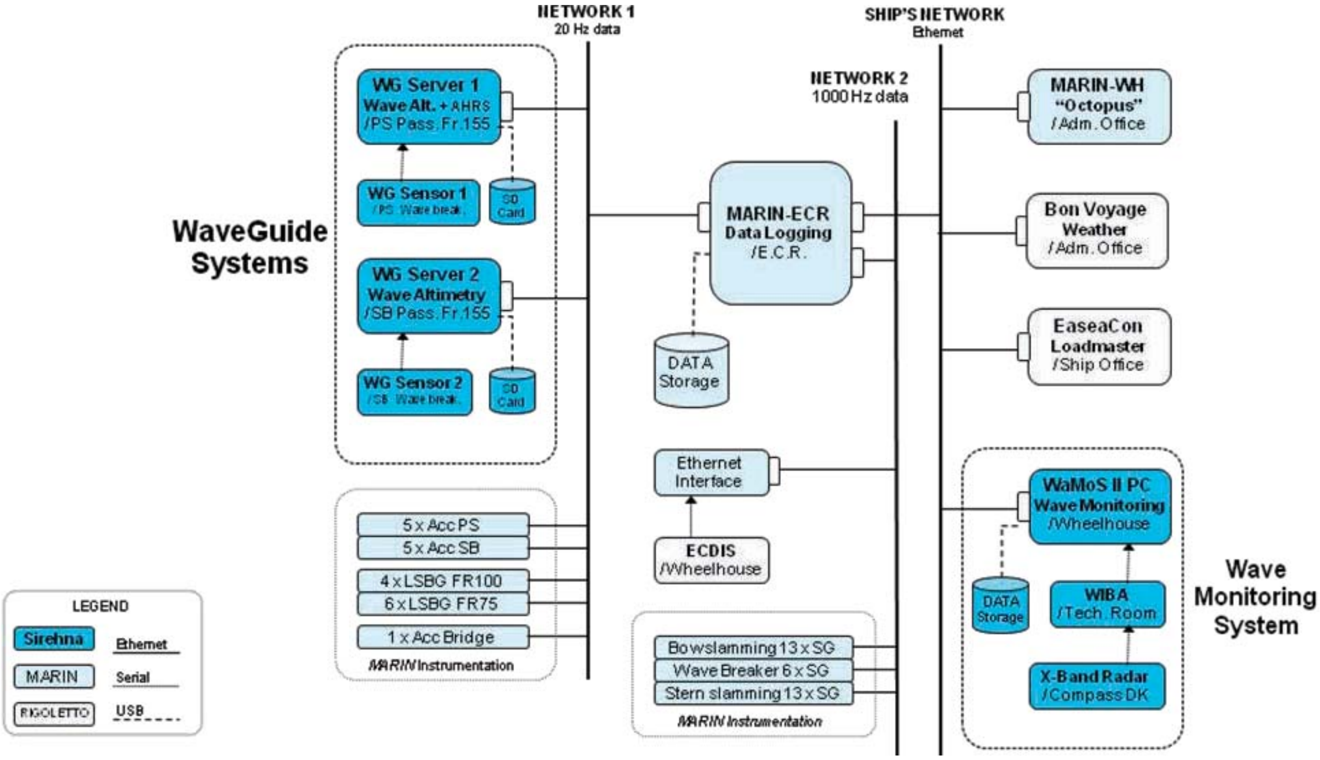

Figure 11 **Instrumentation diagram (Network)**
Slika 11 **Instrumentalna mreža**

side Radac WGS sensor is equipped with an embedded inertial unit to compensate the ship motion. Both units are synchronized by GPS clock and associated with a server installed in the passageways inside the hull. Real time measurements are streamed by Ethernet.

The *Rigoletto* returned from its cruise to Asia with the first full scale sea state measurements. Although systems are still under calibration and tuning process, this first trip brought back some relevant observations during the "Fanapi" typhoon near Taiwan in September 2010.

During the next 2 years of experimentation, this kind of promising sea state measurements in heavy weather conditions should allow improvement of ULCS behaviour understanding.

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