PROJECT FINAL REPORT

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Project acronym: RISPECT

Project title:

Risk-Based Expert System for Through – Life Ship Structural Inspection and Maintenance and New-Build Ship Structural Design

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Final publishable summary report

1 Executive summary

Structural failures of ships are, relative to onshore structures, very common and these contribute to the personal risk levels of mariners, and high pollution and economic costs.

Ships operate in a severe environment that causes corrosion and fatigue cracking of the steel structure of the ship. This reduces the strength of the ship structure, which can only be kept safe by regular inspection and repair of paint coatings, excessively corroded plate and fatigue cracks.

Present inspection planning, and feedback to design, is based on long term experience and, unless any ship-specific problems occur, no account is taken of the needs of any specific ship. Reliability or risk-based methods, applied in other industries, are not usually applied. However information gathered from large numbers of ships, especially if it is compared with theoretical models, could be processed statically and used to improve the initial design and through-life inspection planning of any given ship. This project brings the experience based and statistical methods together and has developed and demonstrated an improved decision making method, for safe, cost-effective structural inspection, repair and design rule improvement of existing ships.

The project set up a methodology, with specified formats/coding systems for ship structure, coating breakdown, corrosion, cracks and structural, reliability and risk analysis results, to enable the acquisition, storing and better use of inspection (and other measured data). Stakeholders are provided with a justifiable decision making procedure, that will gradually become better as more data is collected, for the design and through-life structural management of ships. That research will translate into higher safety, reduced pollution incidents better economics and increased competitiveness of the fleet.

The RISPECT project was an EU funded project involving 11 Partners from different types of organization in 6 different EU countries: universities (Strathclyde, Newcastle, IST Lisbon, Politechnika Gdanska) a class society (Bureau Veritas, Paris), research centres (TWI, Cambridge and ISQ, Lisbon), a software developer (Atlantic Enterprise Solutions, Hamburg) , an inspection company (SE.MA2, Naples) and organizations representing ship owners (CONS.A.R, Naples) and shipyards (Shipbuilders and Shiprepairers Association, Newcastle). The project was coordinated by Strathclyde University, Glasgow.

2 A summary description of project context and objectives

Structural failures of ships are, relative to onshore structures, very common and these contribute to the personal risk levels of mariners, and high pollution and economic costs.

Ships operate in a severely corroding and (metal) fatiguing environment that reduces the strength of the ship structure which can only be kept safe by regular inspection and repair of paint coatings, excessively corroded plate and fatigue cracks.

Previously inspection planning was based on long term experience with usually no account taken of the needs of any specific ship. Reliability or Risk-based methods, applied in other industries, are not good at using information from large numbers of ships to improve the inspection planning of any given ship.

This project provides a better methodology that (on an on-going basis) combines detailed analysis of long term experience from large numbers of ships and the reliability/risk-based methods to provide calibrated design guidance and useful and justifiable through-life risk-based inspection plans. This will lead to better inspections, more important defects being found and repaired, fewer pollution incidents and the saving of lives.

The project evolved partly from a recognition that integrating two apparently different methods for inspection planning should allow better decisions to be made:

1) Inspection, timing and method, for ships has traditionally been based on experience and is essentially determined by class rules. The resulting inspection programs are usually the same for all types of ships. Exceptionally, if severe problems are found, more inspection may be demanded by the classification society for the particular ship and any sister ships. The method has the advantage that it is based on an overview of ship related structural problems but cannot deal well with ship to ship variations in construction or use.

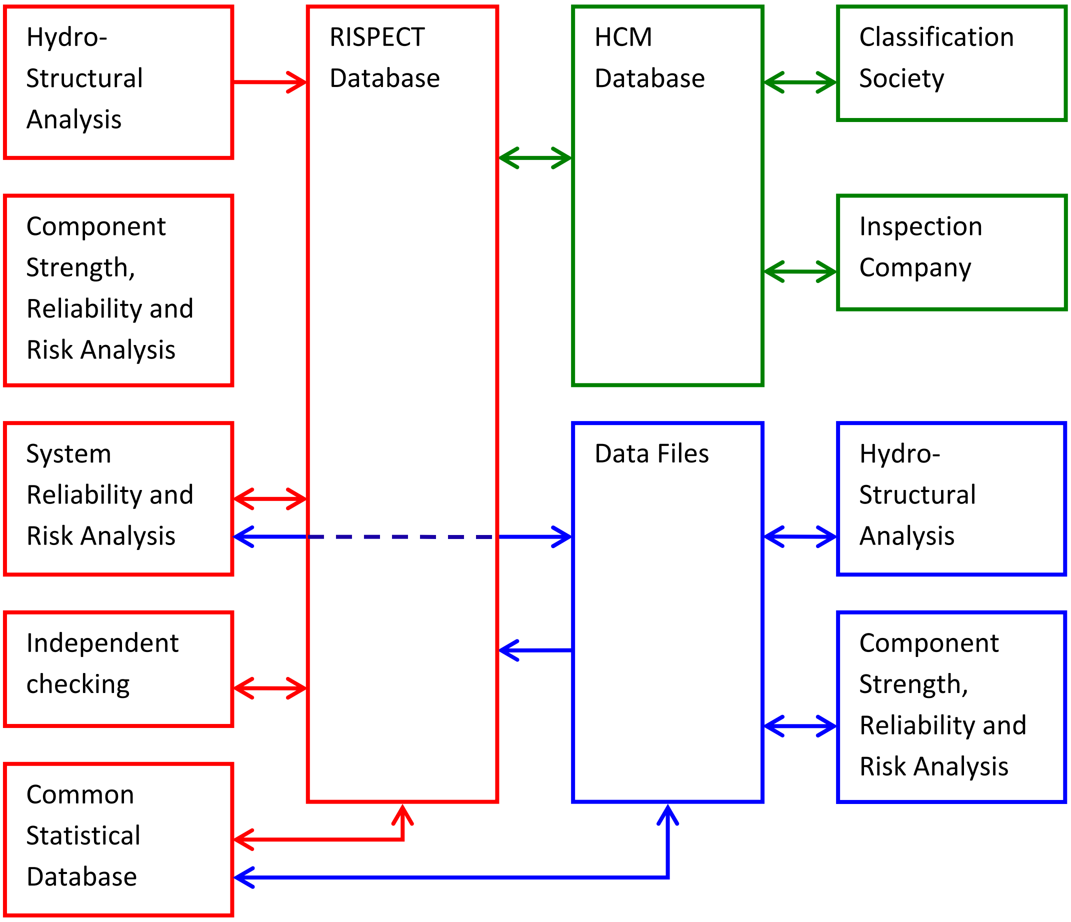
2) Very occasionally, first principles, reliability based, methods have also been used to determine ship reliability and the required inspection levels. These methods have generally been applied to individual component parts of individual ships and can deal reasonably well with the individual part but they do not give a good estimate of the overall reliability of the ship and, crucially, they lack the large personal awareness “experience database” that the traditional, experience-based, methodology uses, so the reliability methods are not calibrated by reality.

This project brought the two methods together and developed and demonstrated an improved decision making method, based on the combination of experience based and first principles, hydrodynamic, structural, reliability and statistical analysis, for safe, cost-effective structural inspection and repair of existing ships. Within the proposed primary methodology the experience base is handled statistically but independent classification society experience (as codified in class rules) is tapped, to provide a ‘common-sense’ check on the purely statistical analysis and warn users of possible shortcomings in the method’s predictions.

The results of periodical structural inspections required by Classification rules are normally transferred to the Classification Societies and managed and analysed by them. However, both for commercial and safety reasons, the validity of a Class certificate is no longer enough for the stakeholders: charterers are increasingly asking shipping companies to adopt certified internal technical management systems (e.g. I.S.O. 9000 – Tanker Management Self-Assessment for tankers) where the demonstration of effective continuous monitoring of the ship's conditions is required together with documentation of the decision making process that determines when maintenance is required. The ship manager therefore has to take charge at a higher level, than has generally been the case in the past, for the technical management of ship inspection and repair planning and optimization. Although this requires more from the ship manager, there should also be a benefit as a result of the improved efficiency, safety and flexibility. The availability to the ship manager of computerised tools for the mapping and the trend monitoring of the coating conditions, corrosion and cracks and damage, especially in the most critical compartments like ballast tanks, cargo tanks and double hall spaces (for tankers) and upper ballast tanks, double bottoms and cargo holds (for bulk carriers), makes this transition much easier and provides a much more effective and justifiable decision making tool.

The methodology recognizes that different data-base structures will be used by different parties and that other parties such as class, specialist inspection companies, shipyards and consultants are likely to be involved in this process. SM2 and BV linked their own database to the system and UGS enhanced and linked existing hydro-elastic and reliability software to RISPECT. This demonstrated that this important capability of the system is practical. In particular the database allows different approaches to describing relevant data to be integrated; this would be much more difficult with a conventional backing file system.

An overview of the software developed or enhanced within RISPECT and the integration of the different systems is show in Figure 1.



Colour codes:

Red: Basic Rispect analysis system

Green: Communication with class and inspection

Blue: Additional communication with parallel analysis system (additional to initial work-scope)

Figure 1 Simplified view of RISPECT software and links to external systems

3 A description of the main S&T results/foregrounds

Fourteen important outputs from this project were identified in the Grant Agreement: Annex 1) that would go beyond the state of the art at the beginning of the project. These were all successfully implemented as described in Sections 3.1 to 3.14 below.

3.1. Tools that will make the best use of all available structural condition and performance data to plan inspections of existing ships.

The application of the system to planning inspections has been demonstrated. The output provides, for local defects (individual cracks or areas of corrosion), groups of defects and the ship as a whole:

1) Reliability = (1 – probability of failure),
2) Risk = (probability of failure x consequence of failure) and
3) Sensitivities i.e. rate of change of reliability or risk with change of input variable.

Low reliabilities or high risks in an existing ship, need to be brought to a satisfactory level through inspection and possibly through changes in ship operating practices or even modification to the structure. The sensitivities allow a ship manager to identify options that are likely to provide the required reliability or risk improvements. The modification can then be input to the program and the reliability and risk recalculated. (In principle the sensitivities can be used to obtain this numerical result more quickly but the non-linearities in individual sensitivities and their interactions with one another mean that a full recalculation at this stage is preferable and in trialling the system has been found that the time for recalculation is short so it is better to do the full calculation.)

The ship manager can consider different options in order to obtain the most cost-effective approach to obtaining an acceptable reliability / risk.

The acceptance criteria for reliability / risk in the shipping industry are not generally agreed at present. However IMO may move from rules to “formal safety assessment” and eventually this should provide a better acceptance criterion framework for these calculations. In the meantime the ship manager would have to specify the acceptance criteria. The ship manager could choose, to implement options that increase reliability in order to reduce dry dock time and associated costs and lack of income. Reliability / risk acceptance criteria have not been studied in the RISPECT work but notional values of reliability required could be $10^{\wedge-5}$ per annum for high consequences of loss of life or ship or a large pollution event to $10^{\wedge-1}$ per annum for minor repairs.

Alternatively if the ship manager specifies the different costs of failures, including safety related costs, and repairs then the program can be used to minimise the overall costs. However this should still be done with some constraints on failure probability and in particular the safety related failure probabilities should be kept as low as reasonably practical (the ALARP principle).

3.2. Tools that will use the available ship performance data for structural design within a goal-based design approach.

The RISPECT methodology is a first principles approach that assesses the loading, strength, reliability and, through the consequences of any type of failure, risk to a ship structural component or the whole structure. In addition the method collects data and calibrates its methods using the collected data. This methodology is an ideal basis for “goal-based” design.

The method uses feedback from visual inspections and thickness gauging inspections. This is good for calibrating fatigue and corrosion models. For extreme loading assessment input is required from full scale stress measurements. It is not clear whether sufficient structural yield or buckling failures will be made available in order to calibrate the structural extreme strength models.

3.3. A standard database structure that can be used by the industry, eventually on a continuous basis for all ships, to gather the performance related information that is needed as a data source for this methodology.

A database structure has been defined that is an extension of the STEP-based TOPGALLANT database, to include a structural analysis "view" or "layer" of the structure and structural analysis, risk and reliability results. The definition document the "Master Document" is extensive and was an early report from the project. It was found that the form of data required for structural analysis was quite different to the form of data used for construction and in the existing TOPGALLANT and HCM standard. In simple terms plates within TOPGALLANT & HCM are the large plates that the structure is made up from and that stiffeners are welded onto. A plate in the structural part corresponds to part of one or more plates that is bounded by e.g. two stiffeners and two frames. This required a layered database where the structure was described in the two different ways in the two layers, but the database facilities could relate information held on the different layers. (Note that this is a big advantage of using a database in comparison with a simple file storage system.)

3.4. Tools for assessing structural loads, stresses and strength simply but effectively.

The methodology to be used for structural analysis was not defined at the start of the project. It was clear that there were two options:

1) Using a relatively simple Finite Element (FE) whole ship analysis.
2) Using a hierarchical approach of global and local models.

The FE approach was adopted and it was decided to use existing MAESTRO FE software. FE analyses of a tanker and bulk carrier were set up using this approach and the data transferred to the RISPECT database. However there were difficulties in using MAESTRO because the MAESTRO file formats were fundamentally changed during the course of the RISPECT project. Because the new formats were much more compatible with RISPECT it was decided to change to the new formats. However this led to delays and in the mean-time, to provide data for the reliability analysis it was decided to use the hierarchical method as well. The tanker was therefore analysed using the hierarchical method and these results were then used by the later RISPECT modules. (This also had the advantage of demonstrating the practicality of linking the RISPECT database to other analysis systems.)

A number of limit states (conditions that may require a repair or may represent a serious failure) have been programmed for RISPECT to model the strength and degradation of the structure within a reliability framework. Owing to delays in providing the software modules for this part, again a parallel development based on improving existing software, was linked to the RISPECT system. The following limit states were then calculated within the RISPECT project:

- Coating breakdown requiring repair (otherwise leading to corrosion);
- Global corrosion, requiring reinstatement of overall cross section properties of the ship;
- Local corrosion, requiring replacement of steel in that area;
- Pitting corrosion, requiring a local repair;

- Pitting corrosion, leading to a leak, with possible pollution or damage to cargo (depending on corrosion and cargo location);
- Fatigue cracks found by inspection and requiring repair;
- Fatigue cracks causing leaks with possible pollution or damage to cargo (depending on crack and cargo location);
- Fatigue cracks becoming unstable and causing overall fracture of the ship hull;
- Overload causing failure of the ship hull by yield.

These limit states were calculated in the RISPECT reliability and risk framework and results produced showing the probability of failure by year over the ship's life, including the effects of inspection. Also overall risks e.g. mean and standard deviation of length of weld requiring repair by year were calculated. (Costs of repairs were also provided so a simple multiplication leads to the financial risk.)

Additional limit states were programmed but not run through the whole RISPECT methodology, these were:

- Local buckling failure and
- Global hull girder failure.

There was considerable innovation throughout this work, in particular in the following areas:

- Using long term and extreme value statistics throughout the system.
- Combining Weibull distributions with different scale and shape factors.
- Calculating and using statistical correlation data throughout the analyses: the "basic correlations" were between 11 loading quantities at each of 7 points along the length of the structure and there were also correlations between strength parameters. The methodology allowed correlations between any force, response or reliability quantities to be determined from these basic correlations. The basic correlations were between normalized quantities, this is because correlations are dependent on mean values and the correlations between the final results are mainly important when the contributing effects are similar in size.
- Classifying structural details so that performance data can be better compared: A completely new classification scheme was developed as previous schemes were not satisfactory for our work.
- Classifying cracks so that predictions can be better compared with observations. There seems to have been little attempt to classify cracks in ship structural details, this is probably a first attempt that could be improved, particularly in nomenclature, although direct graphical entry onto a computer might make the nomenclature less important.
- Provision of background for long term improvement of chemical and physically based coating breakdown and corrosion models. This work identified the form of the models but resulted in large numbers of, presently unknown, parameters. Within the RISPECT programme it was therefore decided to utilise coating breakdown and corrosion models for global, local and pitting corrosion that were based on observations and data collected for the Common Structural Rules.
- Presenting world-wide long term directional scatter diagrams of wave data.: This data was developed from BMT's global wave statistics and converted into Weibull distribution form that could be efficiently used within the RISPECT system and combined with other locations using the Weibull combination methodology derived previously.

- Providing world-wide seasonal distributions of air and sea water temperatures.
- Enabling the efficient calculation of crack propagation from ship details from crack lengths of a fraction of a millimetre to many metres, without requiring time consuming local finite element analysis. This is based on semi-empirical observations of the nature of cracks growing from corners, into plates of differing thicknesses, across beams in bending etc.
- Performing efficient reliability assessment at the component level, allowing for the interaction of loading, strength, and degradation, inspection and repair associated with coatings, corrosion and cracking. This reliability methodology is a combination of level 3 (probability distribution integration) for fatigue and corrosion and level 2 (use of fits to normal distribution) for extreme loading and resistance. To some extent most reliability methods are a compromise between mathematical accuracy and speed. The program has been written to allow the calculation at thousands of locations on any ship structure. This has required some limitation on the number of points used to describe the probability distributions and the iteration to find the failure point in the level 2 analysis has been replaced by checks at a number of predetermined points.
- Providing sensitivities between the reliabilities calculated at different locations: These sensitivities when combined with the correlation data allow correlations of new quantities to be developed from correlations between the quantities producing any result, in a multistage process starting with the basic correlations described above.

3.5. Tools that calculate consequences of local failure and overall hull "system" reliability.

Consequences of local failure were:

- Cost of recoating
- Cost of replacing corroded steelwork
- Cost of repairing cracked steelwork
- Cost of leak requiring internal clean-up
- Cost of leak damaging cargo
- Cost of pollution from a leak
- Cost of fire or explosion following a leak
- Cost of unavailability of ship
- Cost of loss of ship
- Health and Safety costs
- Reputation related costs.

Costs are dependent on the amount of damage (with a detailed breakdown of repair costs being provided by SSA). However repair costs are also subject to uncertainty, so a distribution of costs can be combined with the uncertainty of the damage event.

System reliability calculations were based on the component reliability results and the correlations between them. Correlations and sensitivities are fundamental in the calculation of system reliabilities. Within the project the system reliability calculations were based on the "parallel" component reliability data, not the reliability data from the main reliability program, as this was not available in time. Although the link to the RISPECT database was established, to save time, the component reliability data was obtained directly from the parallel analysis files.

3.6. Tools for determining fleet reliability (e.g. the probability of any one tanker from a fleet having a serious structural failure in any year.)

A methodology for risk based inspection and maintenance decision support for ship managers was developed. This included:

- An approach to calculate the fleet reliability given the reliability of individual ships within the fleet.
- A risk based methodology for inspection and maintenance optimisation was developed. The optimisation algorithm calculated the optimum time of inspection/repair/replace such that maximum risk mitigation is achieved for the entire fleet, given the budget allocated for the purpose.

3.7. A methodology for assessing the quality (in statistical terms) of the conclusions drawn and recommendations made using the tool.

This has been partly achieved: The RISPECT Central Statistical Database provides information on the quality (confidence) of predictions of e.g. crack growth and corrosion thickness loss. The RISPECT system also provides the reliability associated with any maintenance plan. However the project did not investigate the quality of the calculated reliability or overall decision making process.

3.8. Tools based on S-N fatigue analysis and expert system methodologies to provide a check on the primary methodology used within the project.

A rule based strength checking program and S-N based fatigue checking program was written as part of RISPECT. Results from this program are compared manually with the statistical results from the parallel calculation route. A future extension would be to automate the comparison and provide warnings when the comparison is poor.

In addition features to address the following were included within the system:

3.9. The inspection data held by a ship manager will be of interest to class and vice versa. So the system should allow both manager and class databases to be updated from each other's survey results.

The RISPECT database is similar to the HCM (Hull Condition Monitoring) database (a standard developed by BV and GL). Structural description and corrosion data has been successfully transferred between RISPECT and HCM and successfully "looped back", with BV, in order to check that after two conversions the data is not corrupted.

Crack data transfer has been more problematic as the combination of detail description codes and crack description codes is not presently available within HCM, which stores cracks as a series of coordinates, rather than in a codified form. This is something that needs to be addressed in the future if better use is to be made of crack data obtained during survey.

3.10. The ship manager may employ a survey company, again it will be important for the survey information to be collected in the required format and be transferable from the inspection company to the ship owner. If the inspection company plans the inspections it will also require access to the data held by the ship manager.

Similar data, to that transferred between RISPECT and the class society has been transferred between the SE.MA2 (Inspection Company) database and RISPECT. The transfer was performed using HCM so the inspection company would, in future, as an alternative to communicating via RISPECT, also be able to exchange data directly with class using HCM.

3.11. The ship owner will often require reports about the condition of his ship and the maintenance that the manager is undertaking.

The database allows reports to be generated, both of known defects and the likelihood of finding defects in the future. A future extension would combine this statistical data into a standard, more readable, document.

3.12. Other authorities, flag or port state control, may require information.

Again, the database allows reports to be generated, both of known defects and the likelihood of finding defects in the future. A future extension would combine this statistical data into a standard, more readable, document.

3.13. When repair is required an efficient transfer of data from the ship manager to the repair yard is needed.

Important issues were identified here that could improve the efficiency of repairs:

- If the ship database was used to show, graphically, the repairs required before the ship came into the yard, the yard would be better prepared to do the work with, potentially a reduced cost and a faster turnaround of the ship.
- The reduced cost should make the yard more competitive as well as being beneficial for the ship manager.
- The faster turnaround would clearly improve the economics of the ship operation.

3.14. Following repair the database needs to be updated to reflect the repairs.

Having completed the repairs the extent of repair, which will inevitably differ from that anticipated, could be entered back into RISPECT, either by the shipyard or by the manager. The option of the shipyard feeding back the information is attractive, particularly if it is also linked to the shipyards repair planning software and if the modifications are verified by the ship manager’s staff or by the classification society.

The RISPECT database structure was designed to include actual repairs and the RISPECT simulation program can model previous repairs. In the present form of the database a structural plate panel or stiffener is either original or renewed. A future extension could allow for part of a panel to be renewed.

Within the analyses performed the anticipated future behaviour of the ship was calculated including the, probabilistically estimated, repairs.

4 The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

The potential impact of the RISPECT project is largest for seafarers and their families who, if the RISPECT methodology becomes accepted, will benefit from more controlled risks in the course of the seafarer's work.

Others will also benefit from the reduction in pollution risk and the financial risk of a ship loss, that will result from a better understanding of:

1) the safety factors required for initial design and
2) the better inspection planning that will be possible with the data available from RISPECT.

The RISPECT methodology will improve the effectiveness of communications between the parties that manage and maintain ships and this should result in cost savings that may (or maynot) be passed on to the shippers and so may result in some (small) reduction in shipping costs. In either case, and much more importantly, it will ensure these shipments are made with an appropriate level of safety.

5 The address of the project public website, if applicable as well as relevant contact details.

For more information on the RISPECT project, see www.rispect.eu.

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