SAWE Paper No. 3808
Group:

IMPLEMENTING EFFECTIVE WEIGHT MANAGEMENT STRATEGIES IN SHIPYARDS: A PRACTICAL APPROACH

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Abstract
This paper investigates contemporary weight management practices in shipyards, focusing on both weight and center of gravity (CG) estimation, along with the associated follow-up and monitoring procedures. While emphasizing newbuild projects, it also examines modifications and retrofits. Beyond detailing current practices, the paper proposes enhancements and alternative approaches to weight and CG management. It begins with a foundational overview of weight management's definition and significance and extends to encompass weight control principles, procedural frameworks, and weight reporting. The discussion covers estimation methods, publicly available data for estimation, the influence of project types on weight management, uncertainty considerations, and the comparison between CAD data and weight data.

This paper will also compare the current situation with the findings from SAWE Paper 3244 (Weight Control at Ulstein Shipyard, Norway) from 2002, providing useful insights into how weight management practices in shipyards have evolved and where improvements still can be made.

Reference Table

#1: SAWE Paper No. 3244 WEIGHT CONTROL AT ULSTEIN SHIPYARD, NORWAY.

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Weight Control Today

This section of the paper describes current weight control practices in commercial shipbuilding. The data is drawn from extensive experience in the weight control industry and from a survey conducted specifically for this paper, which was sent to various shipyards. While most data come from Norwegian shipyards, similar results have been observed across Europe.

Organization of Weight Control in Shipbuilding

Weight control in shipbuilding varies depending on the size of the shipyard and the type of vessels being constructed.

Smaller Shipyards:
In smaller shipyards, proper weight control is often minimal or nonexistent during the construction of the ship. These yards typically rely heavily on the CAD model and/or weight estimations provided by external ship designers or consultants. If any tool is used for weight control, it is almost exclusively Excel. There is rarely a dedicated person responsible for weight control activities.

Medium-Sized Shipyards:
Medium-sized shipyards usually organize weight control by having different departments report their respective weights to a central person at the shipyard. This person compiles the data into a spreadsheet or dedicated software (such as ShipWeight) to obtain an overall view.

Larger Shipyards:
Larger shipyards often follow a similar organizational structure as medium-sized yards but with more resources. They may have a dedicated weight department staffed with several weight engineers. This allows for a more thorough and systematic approach to weight control. Preferred tools are Excel, commercial software, or homegrown software.

Reporting Procedures During Weight Control

Most of the reporting during the construction project is for internal use at the shipyard to ensure the vessel will meet the specifications set in the construction contract regarding deadweight (cargo capacity), speed, seakeeping, and other characteristics, as well as to ensure the stability calculations for the vessel are satisfactory.

Exceptions exist where the shipowner receives regular weight reports, but this is uncommon in our experience.

Scope and Frequence of Reporting

The scope of weight reporting varies greatly depending on the shipyard, ship type, and the extent to which the vessel is expected to have good margins concerning stability and other deliverables according to the construction contract (cargo capacity, speed, etc.). It often also depends on whether the type of project is something the shipyard has delivered before or if it is a new vessel type for the shipyard.
The frequency of reports typically ranges from once or twice a month to few or none during the construction period, depending on the ship type and project.

Estimation Methods

If we divide the project in 3 main phases; early phase, detailed engineering phase and building phase, the typical estimation methodologies are:

Early phase

In early phase, the following methods for estimation of weight and center of gravity is most common:

1. **Parametric Estimation**: This involves using known ratios (often referred to as estimation factors or estimation coefficients) between weight/center of gravity and other ship parameters to estimate the weight/center of gravity. For example, multiplying the ship's length, width, and depth with a coefficient to get the weight or center of gravity. This can be done in Excel or dedicated software like ShipWeight. The ship is often divided into a breakdown structure, and weight/center of gravity is estimated for a selection of groups within this structure.

2. **Using Previously Built Ships**: This involves taking data from a previously built ship with known weights and adjusting them for the new project based on the differences between the known vessel and the new one. This requires the ships to be relatively similar in type and size.

3. **Combination of Methods**: Sometimes a combination of the above methods 1 and 2 is used, estimating a "baseline ship" using parametric estimation and then adjusting for specific equipment and capacities for the new vessel.

4. **Estimation by Outfitting Degree**: Early estimation can also be done by creating an early model of steel weights (using ExpressMarine or NAPA Steel, or estimation in Excel) and then estimating the total weight using an "outfitting degree" to estimate remaining weights. This means estimating the steel and assuming it constitutes, for example, 60% of the total ship weight.

Sometimes estimates can be calculated using different methods where the differences in the results are compared and investigated. This reduces the risk of the estimate.

Detailed Phase

In the detailed phase, weight and center of gravity information usually come from one or more of the following sources, improving and/or verifying early phase results:

- Structural weights and centers of gravity from early modeling tools like NAPA Steel or ExpressMarine.
- Structural weights and centers of gravity from detailed 3D modeling as it is completed.
- Detailed equipment lists with weights from subcontractors.
- For sister ships, some skip early phase estimates and go directly to the construction phase using the early phase estimates.

Construction phase

In the construction phase, estimated and sometimes verified weights come from:

- Weighing modules and units during crane lifts.
- Subcontractors.
- Nesting (burn outlines) and detailed 3D modeling.
- Estimating "unidentified" weights from various disciplines.

Use of Publicly Available Experience Coefficients

There are few publicly available experience coefficients for estimation. While some coefficients and curves are found in literature and academic articles, their value is often limited because the background of these factors and curves is rarely known, making it difficult to understand the assumptions, accuracy, and specifics of the data used. It is therefore strongly recommended that shipyards use their own experience data as much as possible to generate experience coefficients.

"One of a kind" versus Building Series/Sister Ships

"One of a kind" projects are challenging because they often have little to no historical weight data to form the basis for experience coefficients and estimation. This makes it difficult to use the estimation methods described above, both in terms of parametric estimations based on own experience data and adjustments relative to previously built ships.

The lack of relevant experience data for similar vessels will affect the ability to estimate at a high-level weight group (total lightship, total hull, total equipment, total machinery), but can be compensated by estimating weight groups at more detailed levels, such as various machinery groups based on installed power, different hull areas, and vendor weights for special equipment.
Conversely, for series/sister ships, there is typically data and experience from previous builds, providing a much better basis for accurate early-phase estimation.

Uncertainty in Using Experience Coefficients

Uncertainty when using experience coefficients varies for different equipment groups and/or disciplines based on how much experience data the shipyard has for each group, and the extent to which the accuracy of these historical data has been verified. Some groups can be verified during construction by checking measured values from crane lifts (and other weighings) against values in the weight database, while others may be difficult to verify.

If a detailed and accurate 3D model of the structure is available, it can often be relied upon and sometimes verified against displacement/heeling tests of the hull before outfitting.

For some groups, good weight information can be obtained from subcontractors, while for others, this may be lacking or unreliable.

For especially demanding prototypes, extra "lightship surveys" are sometimes conducted, updating all weight lists with installed/not installed items, followed by an internal heeling test to establish a reference point, attempting to verify the steel weight and major components onboard at that time. For offshore constructions, it is not uncommon to weigh modules after a detailed follow-up on what is installed. These control weighings can also verify transverse and longitudinal center of gravity.

Using Uncertainty Margins in Shipbuilding Projects

It is common to add uncertainty margins for weight and center of gravity in shipbuilding projects. The size of these margins depends on the ship type, how critical weight/center of gravity is for that type, and the confidence in the estimates. This can also vary by project based on how weight-critical it is.

Typical weight margins are around 3–7%, while for the vertical center of gravity, they can range from 0.25 to 0.5 meters, but this can vary.

It should be noted that there are significant differences in how shipyards define safety margins, especially concerning weights often added as a percentage of another weight, such as weld weight. Some shipyards include this as a separate weight in the estimate and add the uncertainty margin on top of the total, while others include it as part of the overall percentage uncertainty added at the end.

Hedging Against Inaccuracies by Adding Large Margins

It is not possible to hedge against inaccuracies by adding large uncertainty margins. The main reasons for this can be summarized as follows:

- **Weight Margin**: Adding a weight margin means designing and building a larger ship, which is unfavorable for construction and operational costs. If the margin turns out to be unnecessary, additional ballast might be needed to achieve the required stability and seakeeping characteristics.
- **Vertical Center of Gravity Margin**: A margin for the vertical center of gravity, if not needed, can result in overly good stability, making the ship too "stiff" with abrupt movements, potentially uncomfortable or even unusable. Designing for this margin might require adjusting the ship's width to achieve the desired margin.

Draft Change as Margin

There are projects where draft is the critical factor for weight increase, especially for vessels navigating rivers or shallow waters or docking at berths with depth limitations. Changing the draft might be disadvantageous for a hull optimized for a specific draft and speed, affecting the power needed to maintain a given speed. However, cargo capacity, speed, and/or stability are more usually the critical factors for weight or center of gravity errors.

Significance of the 3D Model for Weight Monitoring

The development of a 3D model often significantly impacts weight monitoring, particularly for structure (steel/aluminum), but also for pipes, cables, machinery, and interior. However, equipment and interiors are not always modeled with weight information for use in weight monitoring. For pipes, cables, and structure (steel/aluminum), it is crucial that the shipyard and modelers are aware that the model will be used for weight monitoring and follow guidelines to ensure accurate results. A detailed and properly set up 3D model with correct materials and densities, and appropriately modeled components (e.g., pipes modeled with hollow sections), can provide a valuable contribution to weight monitoring.

That said, 3D models can contain various sources of errors, and using a 3D model uncritically is risky. Additionally, a 3D model itself is not a weight monitoring tool but a source for weight monitoring, which cannot replace dedicated databases and systems for weight control.

Transition from Estimated Weight to Identified/Asbuilt Weights

There is no standard procedure or terminology for weight monitoring. An "identified" weight is not a universally defined concept and can be used differently by various shipyards. It often refers to a weight associated with a specific object rather than being part of a margin or based on uncertain or unverified experience data. It might still be estimated, but it is linked to an object or system.

For many shipyards, steel weights from a detailed 3D model can be considered identified weights, even if some simplifications are involved in the modeling. Similarly, weights from subcontractors or equipment lists from vendors, despite having potential uncertainties and needing verification, can be classified as identified weights. Other shipyards might require detailed measurements or weighing of components to consider weights identified.

Normal Practice for Weight Control During Construction Phase

During the construction phase, weight monitoring typically involves receiving weight information from various disciplines and departments at specified milestones or intervals. This information is then reported to the individuals responsible for weight control. Ideally, this reporting follows an agreed-upon format and includes specified quantities for the weights, along with other relevant information crucial for weight monitoring. Often, this information pertains to weights defined as "identified," or the unit weight for a specific object. It is particularly important for the disciplines to also provide their best estimates of the "remaining weights," those that are not "identified," as this is the only way to project a new expected total estimate.

When the reported weights are compiled to provide a new total estimate of weight and center of gravity, it results in what is often called a revision of the weight and center of gravity estimate. This typically materializes into one or more reports, ideally showing the following:

- The latest and most updated total estimate for the vessel's weight and center of gravity.
- Status of the margins.
- The latest and most updated estimate for selected subgroups of the vessel (SFI codes, disciplines).
- Status of the "maturity" of the weight database (proportion of estimates, CAD weights, weights from subcontractors, weighed weights, etc.).
- An overview of the changes since the last revision (weights altered, added, removed).
- An overview of trends for all revisions to date, shown in graphs and tables, including remaining estimates and margins, not-to-exceed values, and similar metrics.

- An overview of change orders and their impact on weight and center of gravity.

Weight Control Today versus 22 Years Ago

In this section we will compare the findings of how weight control is typically carried out today with the procedures outlined in the SAWE Paper No. 3244 “WEIGHT CONTROL AT ULSTEIN SHIPYARD, NORWAY". (#1)

The paper was describing the results from a project launched at Ulstein Verft AS, a shipyard in Norway, to improve weight control activities. The paper is therefore not describing the normal process 22 years ago, but the improved process resulting from the project.

Some, but not all the subjects in this paper will be compared and discussed below.

Definitions, Terminology, and Motivation for Weight Control

Weight Control Definition

In the SAWE paper from 2002, weight control is defined by three main phases:

- Weight estimation/budgeting (before contract)
- Weight tracking/monitoring (during building)
- Structuring of as-built data (after building)

This definition holds water also in 2024, and we refer to the original paper for more details, but we may note that weight estimation as an activity for certain weights may also happen in the tracking/monitoring phase, but then it is referred to as an activity not a phase.

Weight Control Principles

The weight control principles outlined in the SAWE Paper No 3244 we find to still be valid, and again we refer to the original paper for details, but we will list the principles here:

- Handle margins (define them clearly)
- 50/50 Estimation Principle (your estimate should have equal chance of being too high as to being too low)
- 100% Reporting (always report 100% of the weight group – estimate missing weights)

Motivation, why is Weight Control Important

Again, the SAWE paper from 22 years ago provides good reasons also for today’s shipbuilding as to why doing weight control is important. Below is a list the main points and referral is made to the original paper for more details:

- Avoid Contract Claims (fulfill direct requirements in contract)
- Fulfill vessel specifications (fulfill indirect requirements in contract)
- Cost Control (weight and cost is tightly linked)

- Input for Operations (launching, lifting, etc.)
- Documentation (document change orders and impact)
- Improve Future Weight Estimation (gather historical data)
- Sale and Promotion

Weight Control Procedures

Organizing the Weight Control

SAWE Paper No. 3244 outlines an organization of the weight control much in line with how it is being organized today. This means one central person to receive weight information from the departments and disciplines.
Back then, as today, Excel was the preferred vehicle for transferring weight and CG data from the departments to the central source.

Weight Information from CAD Systems

Utilizing weight information from CAD System, especially 3D modelling, seems to be much more important today compared to 2002. Although 3D systems are described as a source of weight information also in the paper from 2002, it seems to play a much larger role in today's shipbuilding in weight estimation, tracking and monitoring.

Weight Reporting

The weight report outlined in the SAWE Paper No. 3244 is similar to what will be found in the best weight reports today. The main information as listed in this paper are these:

- Summary and conclusion
- Updated weight information
- Trend analyses
- Budget and change order corrections.
- Weight information for special operations
- Listing of weights

What is missing from this list compared to today's best practice is information on maturity status of the weight database.

Enhancements and Improvements

Almost all the results from the project conducted by Ulstein Verft AS over 20 years ago remain valid as best practices today. At the time, this was a pioneering project in Norway, significantly ahead of the general weight control practices. Since then, more shipyards have adopted and enhanced their weight control management, yet there is still potential for further improvements.

Establishing Weight Report Management Procedures

Many shipyards today could benefit from better utilizing existing publicly available knowledge and procedures for weight control management. This involves defining and establishing weight control documents and procedures in line with the guidelines presented in this paper, SAWE Paper No. 3244, and other publicly available articles and documents.

Utilize New Tools

Dedicated Tools for Weight Control

Commercially available software tools for weight control can greatly assist shipyards in managing weight control. These tools offer a more structured and secure way of handling data compared to spreadsheets and may include additional functionalities such as weight distribution analysis, gyration calculation, and other weight control calculations beneficial during the design and construction process. Moreover, they often enhance the utilization of historical data and provide quality control and assurance of the weight data.

New Tools for Gathering Information from Departments and Disciplines

In nearly all cases, transferring weight data from various departments and disciplines to the central weight control personnel is done via Excel. However, new technologies are emerging that offer commercially available solutions for this process, allowing data input through web interfaces. These solutions can help reduce input errors and lessen the effort required to verify spreadsheet entries.

Democratization of the Weight Data

Traditional weight reports can be supplemented with information sharing made available through new technology and web services. There are commercially available tools for this purpose, as well as the option to implement generic solutions like Microsoft Power BI and similar tools.

Using 3D Model as Your Weight Management Tool

As 3D modeling becomes more common and accessible, shipyards are increasingly relying on 3D models as the primary source of weight information and sometimes the main tool for weight control. Although 3D models contain valuable weight information, there are some pitfalls to be aware of:

- Modeling is often done for purposes other than weight calculations. For example, a cable tray modeled as a solid may be suitable for drawings, but the weight calculations will be significantly overestimated.
- Correctly assigning materials and material densities is crucial and errors in this process can lead to serious inaccuracies.
- Temporary items may be mistakenly included in the weight output from the 3D model.

A 3D model will not have sufficient functionality to provide weight reporting according to best practices, nor be able to properly include the weights that are not modelled. It should therefore not become the main tool for weight control but remain a source of information for the weight control management.

Conclusion

Weight monitoring in shipbuilding is a critical process for ensuring that the vessel meets contractual and regulatory requirements. It involves a combination of estimation methodologies, regular reporting, and meticulous tracking through various project phases. The use of 3D models, inclining tests, and detailed follow-ups ensures that weight and stability are maintained within acceptable margins, ensuring the safety and functionality of the final vessel. Over the last 20 years or so, there seems to be no fundamental change in how weight control is managed, and the evolvement of the subject has not been significant. Still, this is a field with a potential of large improvements for many shipyards simply by utilizing existing knowledge and tools.