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# Review of experiments and calculation procedures for ship collision and grounding damage

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ABSTRACT

The paper presents a review of experiments and calculation procedures for the resistances of ship structural components subjected to impact loadings. The purpose of the paper is to highlight the importance of large-scale collision and grounding experiments and to discuss the technical difficulties and challenges in analytical, empirical and numerical analyses. Experiments on ship structural components are benchmarks and baselines, used to propose analytical or empirical formulae for the structural energy absorptions and/or to validate numerical analyses considering the actual structural and material characteristics. In recent literature, analytical and numerical calculations provide relatively accurate prediction of the purely plastic responses of ship structures under impact loads, but universal approaches have not been found for fracture predictions. The existing formulae for failure criteria still show limitations when evaluating material fracture in various damage patterns. Recently, semi-analytical approaches have been developed to evaluate the relationship between the absorbed energy and the damaged material volume, taking into account the structural arrangements. It seems that these semi-analytical methods often show better accuracy than the numerical simulations when predicting the experimental results.

## 1. Introduction

A review paper [1] on ship collision and grounding analysis procedures advocating for standards for design against accidents was published in 2010 and the paper emphasizes that procedures should be developed to assess ship's performance in collision and grounding accidents. In evaluation of collision and grounding events, one of the key issues is an accurate prediction of the damage extent of ship structures. The main focus of the present paper is to review the literature on experiments and calculation procedures for the internal mechanics of ship collisions and to propose further research topics.

The evaluation methods for internal impact mechanics include experiments, empirical formulae, analytical methods and finite element simulations. Their advantages and disadvantages are summarised in Table 1, and the analysis procedure for impact strength of ship structural components are presented in Fig. 1. Two decades ago, a potential design procedure for grounding and collision was proposed by Amdahl et al. [2]. Ship grounding was categorized as two types: vertical penetration referred to as “stranding” and horizontal sliding referred to as “raking”; the internal mechanics of ship collisions can also be separated into two types: side penetration referred to as “side collision” and bow crushing in head-on collision referred to as “bow collision”.

In the literature, the investigated ship structural components include plates, stiffened panels, web girders, web and stringer

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**Table 1**
Available methods for structural impacts.

| Method | Analysis | | Result | | |
|---|---|---|---|---|---|
| | Effort | Difficulty | Energy | Load | Stress |
| Experiment | Expensive, time consuming | Scaling effect | X | X | X |
| Empirical formula | Hand calculation | Lack validation | X | | |
| Analytical formula | Hand calculation | Lack validation | X | X | |
| Numerical simulation | Specialty, time consuming | Definition of material fracture | X | X | X |

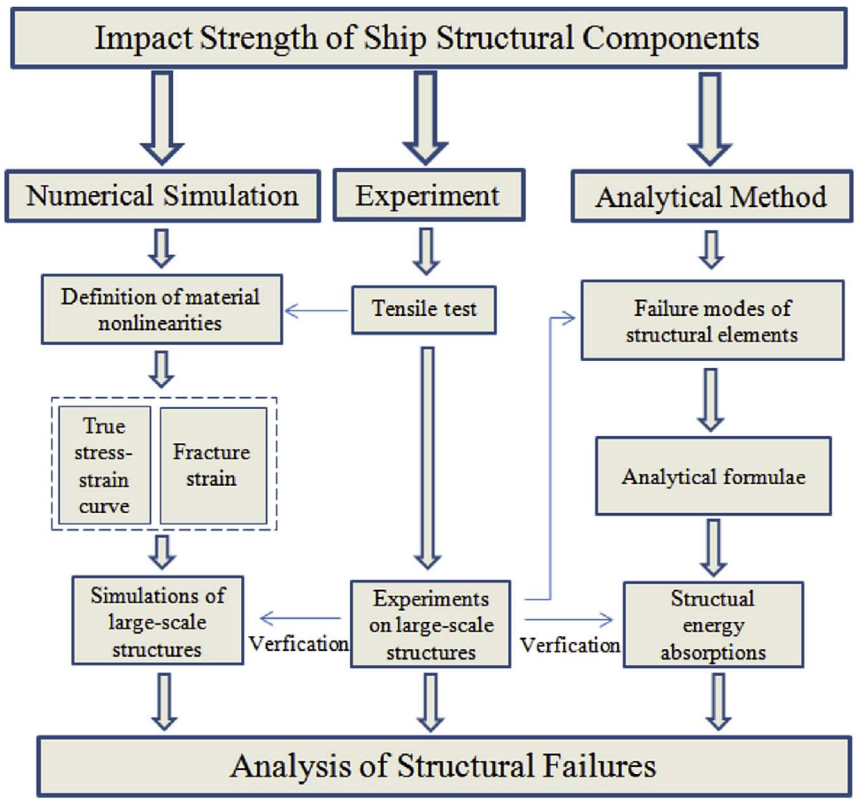


**Fig. 1.** Analysis procedure of impact strength of ship structural components.

intersections, stiffened decks, single bottoms, double-hull sides and bottoms, straight bows, bulbous bows, etc. The failure modes associated with internal mechanics of ship collision and grounding can be described by plate tension, folding/crushing, tearing/cutting, and sliding, etc. The failure modes involved in ship side collision, bow collision, stranding and raking are summarised in Table 2.

Real life accidents are influenced by many components and unknown variables and consequently difficult to analyse in detail. However, damage and failure patterns from collision accidents provide the true pictures in revealing the ship damage mechanisms. Fig. 2 shows examples of recent collision accidents. It is fundamentally important to consider actual ship collision scenarios and ship structural scantlings and arrangements when conducting collision experiments.

**Table 2**
Internal mechanics in ship collisions and grounding.

| Scenario | Main failure mode of plate elements | | | |
|---|---|---|---|---|
| | Tension | Folding/Crushing | Tearing/Cutting | Sliding |
| Side collision | X | X | | |
| Bow collision | | X | | |
| Stranding | X | X | | |
| Raking | | X | X | X |