# Collision Safety Analysis of Offshore Wind Turbines

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**Abstract:**

Some offshore wind farms in Europe have been built and numerous projects are on the drawing tables. It is necessary to study the effects of these wind farms with respect to the safety of shipping in order to estimate the related risks to people, ship traffic and the environment. Here the formal risk definition is the product of collision frequency (collision rate) and collision consequence (size of ship damage or emission of harmful substances).

This paper puts emphasis on the methods of the determination of the consequences. For offshore wind farms within the German Exclusive Economical Zone (EEZ) the so-called “Collision Friendly Foundation Design (CFFD)” is required by the responsible authorities. In case of a ship collision with such a foundation type, the ship will not be damaged or more generally spoken emission of harmful substances will be minimal.

Within this paper ship/offshore structure collision modeling is presented as an example for a non-automotive application of LS-DYNA. Shortcomings within the code special to this and other shipbuilding applications are emphasized in order to highlight the need for further development of the code besides automotive applications. LS-DYNA is the most commonly used code in ship crashworthiness analysis.

**Keywords:**

offshore wind turbine, ship, collision, risk evaluation

 

## 1 Introduction

Collisions of ships and offshore wind energy turbines (OWTs) constitute a considerable threat to the environment. It must be considered that in a collision incident parts of the ship structure are damaged. Leakage of operating supply or cargo (e. g. oil or chemicals) is possible. In a worst case scenario the ship could break apart and sink.

The research project referred to in this paper was aiming at a numerical evaluation of several collision scenarios between different ship types and three exemplary types of foundation structures. It was funded and initiated by the German Federal Ministry of the Environment. The resulting conclusions were supposed to lead to an evaluative scheme to determine the mechanical properties of OWT foundation structures concerning their crashworthiness and their ability to conserve hull integrity in ship collisions. These guidelines shall be used in the process of the approval of OWTs.

A stochastic analysis of the probability of collisions was not the aim of the project although it is necessary to link both an analysis concerning the probability of a collision and a consequence analysis to determine the risk.

In an analysis done by the Federal Environmental Agency on preventive action in events of failure in offshore wind parks, a single hull oil-tanker of 160,000 dwt was proposed by the German Federal Environmental Agency to be the design ship in accidental limit state (ALS). Also, a damage of three cargo tanks was estimated as being likely, which means an amount of 54,400 tons of spilled oil to calibrate necessary preventive action to be taken into consideration.

The aspect of collision safety is mostly treated in connection with the design of tankers. For this type of vessels, there is an international binding agreement (MARPOL 73/78 Annex I, Directive 13F), which determines the minimum dimensions of double bottoms and double hulls. Additionally, the European Union decided to phase out single hull tankers more quickly to reduce the environmental impact of collisions with tankers.

The state of the art in simulating collision and grounding events were enhanced by scientific projects, which were initiated after the spectacular tanker wreckings of “Exxon Valdez” and “Braer” and set forth e. g. in connection with the construction of the Great–Belt–Crossing. In these projects, empirical, analytical, and numerical methods were applied and many experiments were executed. Several experiments and analyses are described in Zhang’s dissertation [1], which also features an extensive reference list on the field of collision analysis.

Between 1995 and 1999 two projects were conducted at Germanischer Lloyd and Hamburg University of Technology (TUHH) that dealt with the safety of double hull tankers concerning collision and grounding [2], [3]. Apart from this, there is a worldwide interest in the limitation of risks in collisions. An overview on the actual state can be found in the ICCGS conference proceedings [4].

 

## 2 Collision Scenario

Calculations were carried out for four different OWT support structures: A mono pile, a jacket, and two tripod foundations (North Sea and Baltic Sea locations).

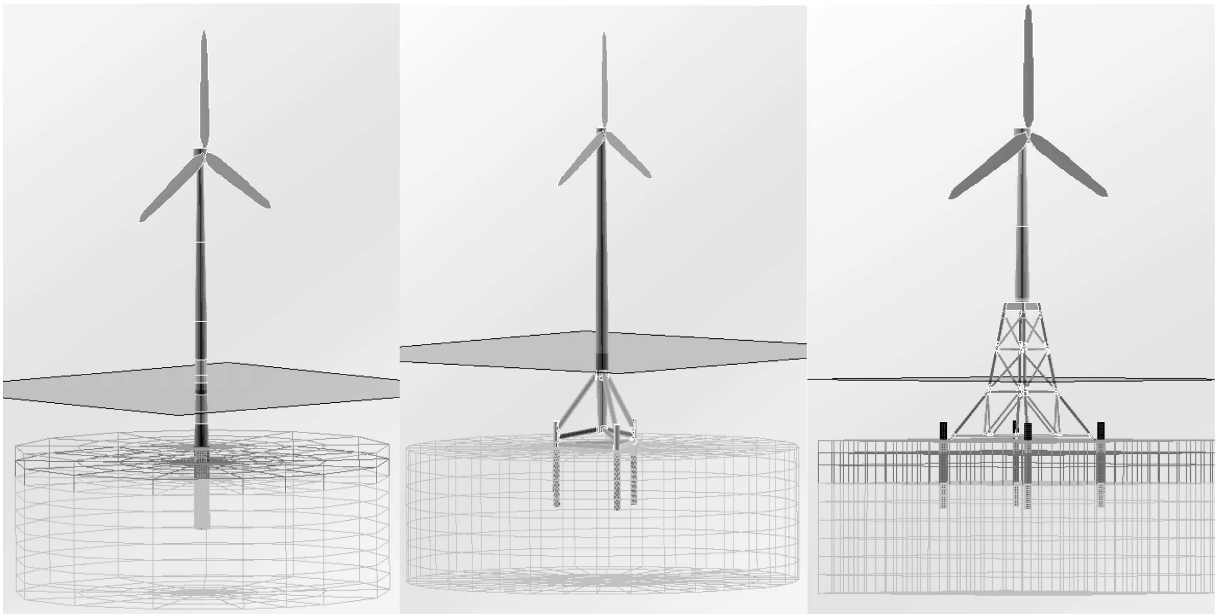

*Figure 1: OWT Support Structures*

In cooperation with Germanischer Lloyd, ship types were selected for the analysis of the collision scenarios. The decisive factor was the commonness of the types. As a basis for this, results from Germanischer Lloyd regarding maritime movement on the North and the Baltic Seas were used [5]. The percentage of the different ship types was calculated for the years 1995 to 1999 and extrapolated to the year 2010. The absolute number of maritime movements rises from 373,023 per year in the time between the years 1995 and 1999 (mean value) to 450,086 in 2010 (estimated).

A 31,600 tdw double-hull tanker, a single-hull (150,000 tdw) tanker, a container ship (2,300 TEU) and a bulk carrier (170,000 tdw) were selected.


*Figure 2 Ship types used in analysis*

# 3 Collision Model

Numerical analysis of ship to OWT-collisions basically is an extension of the calculation of ship to ship-collisions. When considering ship bow to ship side collisions, the bow of the colliding ship can be assumed to be rigid [3]. Both structures in a ship to OWT collision are to be considered deformable. Additionally, the interaction of the support structure and the foundation soil is to be taken into consideration.

The numerical model for the collision analyses consists of two main parts:

1. the OWT comprising machinery and support structure including soil-foundation interaction, see fig. 2, and
2. the colliding ship including the surrounding water.

Only side impacts of the ship with the OWT were taken into account for two reasons. Firstly the ship side is of lower strength and stiffness and thus more vulnerable compared to the fore and aft. Secondly it is more likely that the colliding ship is a drifting ship and thus ramming the OWT sideways. Motions (rotations) of the ship around the OWT were not considered. These are conservative assumptions leading to more severe damages than in reality.

## 3.1 Ship

Not the whole ships but only one or two cargo holds were discretized as finite element models to reduce model size and calculation time. The remaining parts were idealized as rigid bodies with attached mass and inertia.

### *3.1.1 Geometric Model*

As an example, a section of the FE model of a double hull tanker is given below.

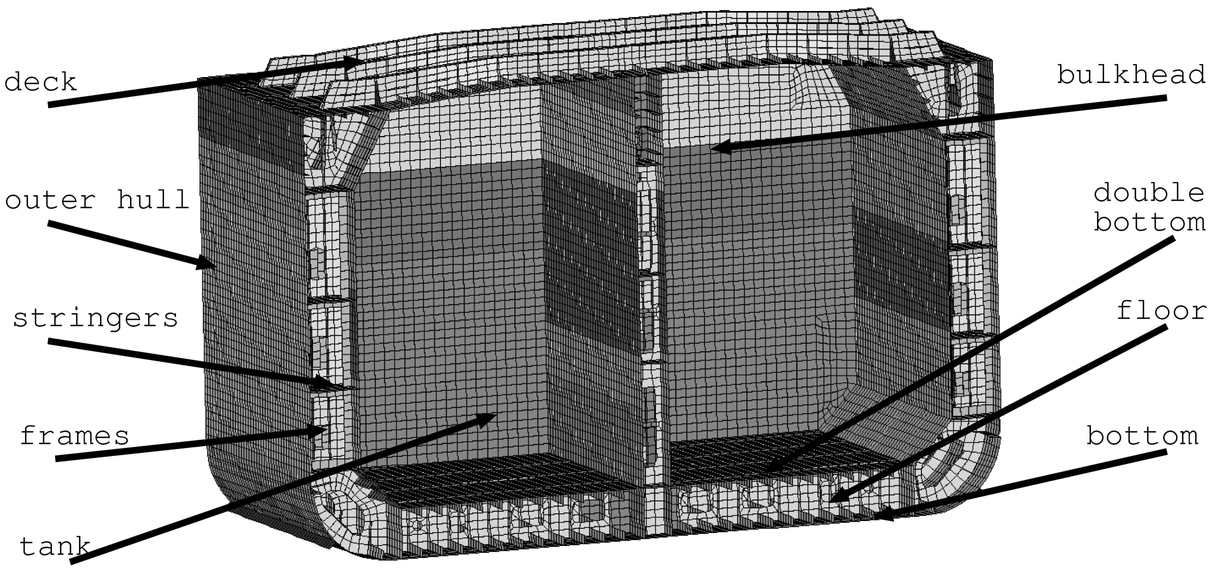


*Figure 3 Section of a double hull tanker*

### *3.1.2 Ship Motion*

The ship types considered are very long (up to 300 meters) compared to the width of the OWT foundation (up to 30 meters). Therefore, the ships were not fully discretized. Only one or two holds were modeled with finite elements. The rest of the ship was modeled as a rigid body connected to the FE-model at the outer nodes of the most forward and rear section of the FE model (see Fig. 3).

In addition to this, the ship's motion before and during the collision which is driven by hydrodynamic forces was taken into consideration. According to the potential theory, the hydrodynamic forces are determined quite easily in a harmonic agitation of the hull. The procedure has already been implemented in the present version of LS-DYNA. The calculating method used here is similar to the procedure in [6].

 

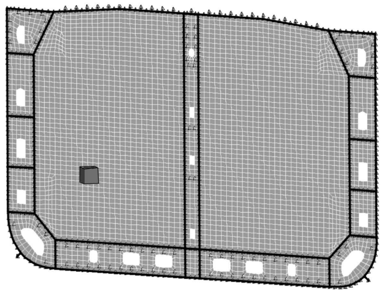

*Figure 4 Connection of deformable and rigid parts, connection nodes are drawn in black.*

### 3.2 Offshore Wind Turbine

A description of the different parts an OWT consists of is given in the figure below.

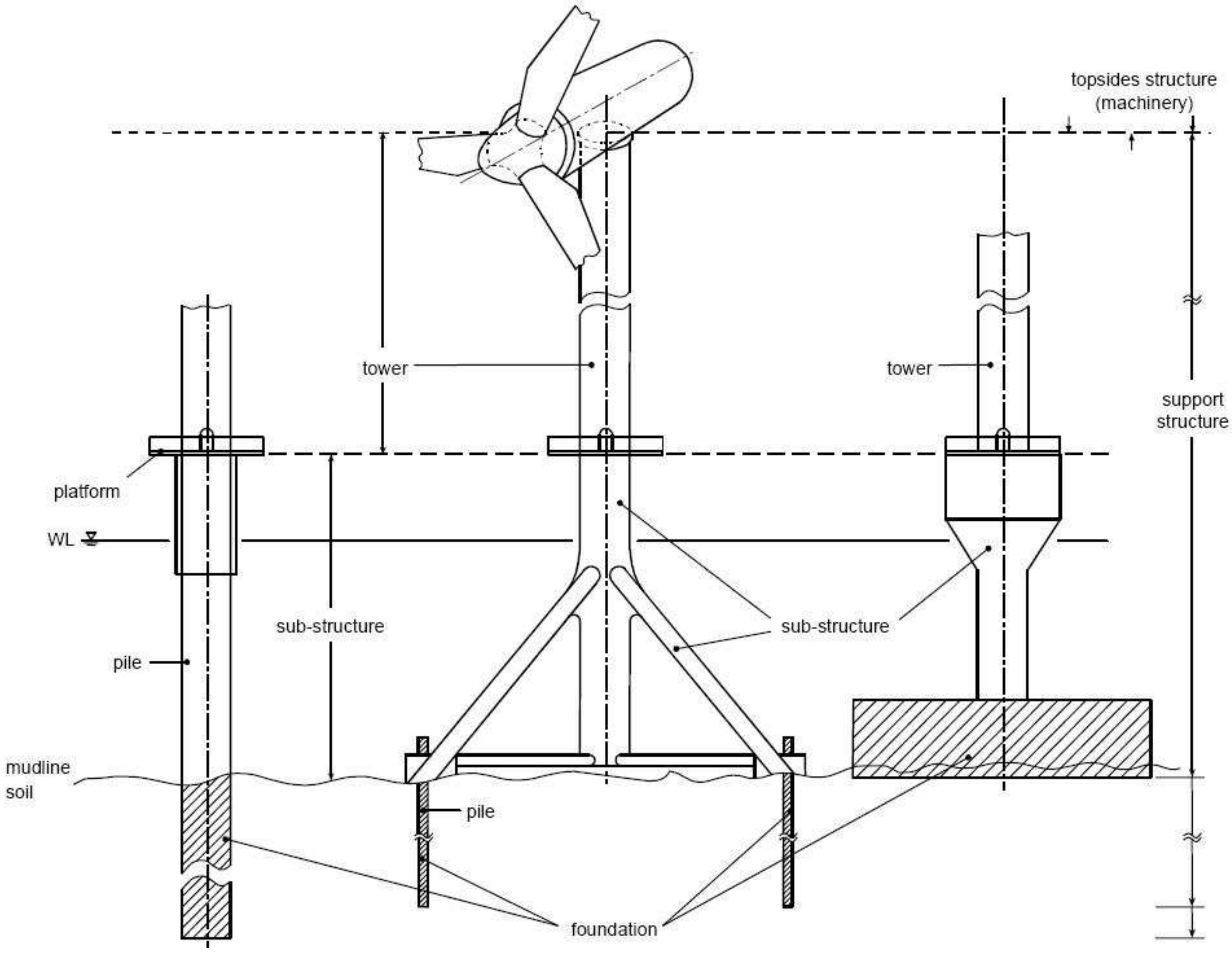


*Figure 5 Definition of offshore wind turbine sections*

#### *3.2.1 Steel Structure*

The tower, sub-structure, and foundation piles were modeled with thin shell elements according to design drawings obtained from OWT manufacturers. There is a grouted connection between the tower and the sub-structure, i.e. high strength concrete is filled into a gap between the two tubes. This part was idealized with solid elements and isotropic elastic material parameters for concrete.

#### *3.2.2 Machinery*

This part has not been of much interest and was therefore idealized as rigid body with attached mass and inertia only.

*3.2.3 Soil Structure Interaction*

The pressure and friction interface between pile(s) and surrounding soil is described best with a "SOFT-2" surface to surface contact algorithm which allows for separation and therefore carries no tension.

## 4 Procedure

### 4.1 Implicit (Static) Pre-Calculation

1. Soil is not stress-free prior to construction work. Therefore, a stress field has to be initialized before calculation. Unfortunately, the LS-DYNA function *LOAD_DENSITY_DEPTH does only initialize hydrostatic pressure. Here we need different pressure values in vertical and horizontal direction connected by a coefficient $K_0$. ($K_0$ is somewhat around 0.5).
2. The OWT model has to be loaded with gravity and other forces as seen in figure 6:

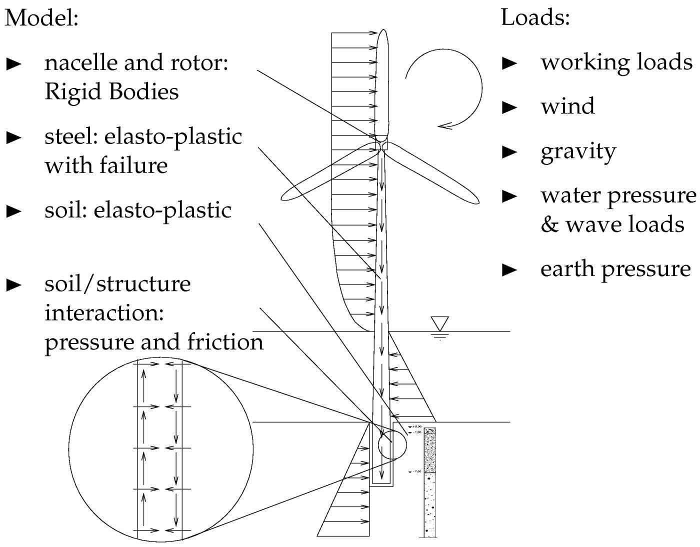


*Figure 6 implicit pre-calculation*

### 4.2 Restart Problem

As the function *BOUNDARY_MCOL is needed in transient analysis to calculate the ship's motion and it is impossible to (re-)start a calculation at a time other than 0.0 s with *BOUNDARY_MCOL, stresses and strains have to be saved in a dynain file. Also, nodal interface forces have to be output for later input via subroutine usrfrc.

 

### 4.3 Dynamic Collision

For the calculations, the following boundary conditions were set up:

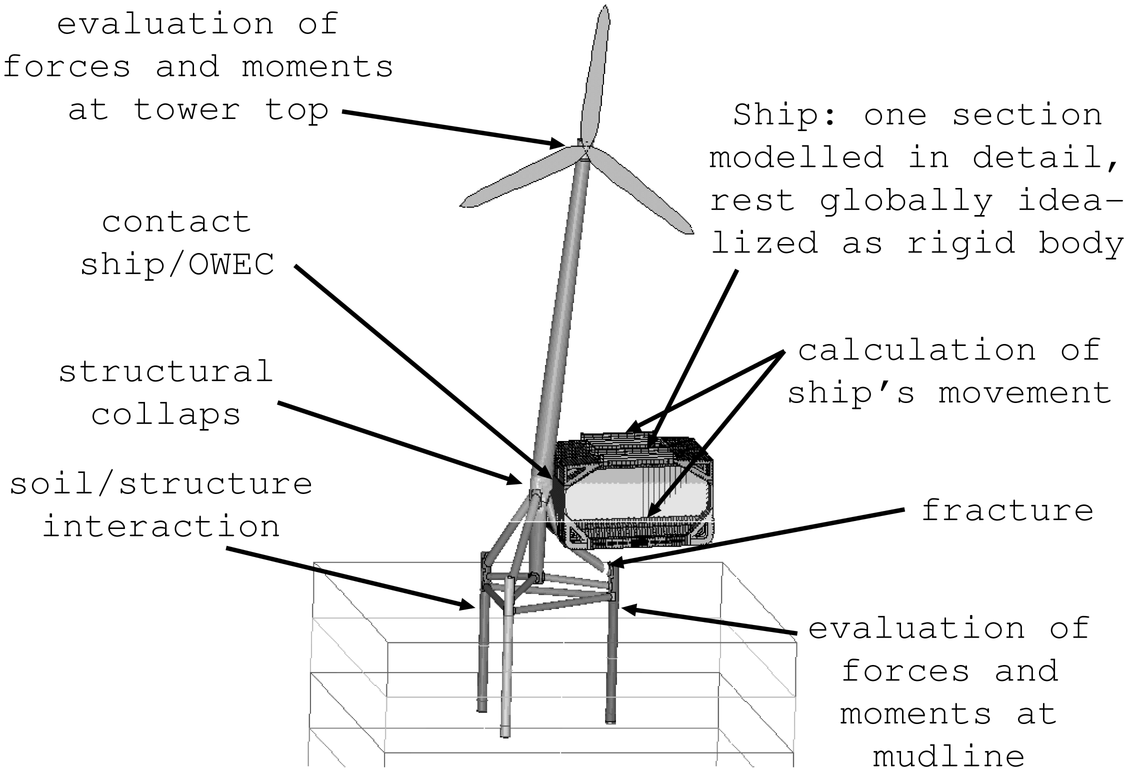


*Figure 7: collision: input data, parameters, and output data*

For standard cases, a drift velocity of 2 m/s (approx. 4 knots) has been assumed, in individual cases, collisions with 3 or 4 m/s were simulated to evaluate the influence of a variation in initial kinetic energy. The drift angle was set to 90°. Sea conditions were n ot taken into account.

Failure of individual modules is the decisive part in the simulation. There are different failure modes:

Ultimate Strength: In the constitutive model for steel, a failure criterion is implemented that considers an element ruptured if a certain amount of effective plastic strain is reached. This failure strain depends on the initial geometry of the finite element. Peschmann [3] gives values for certain element length/thickness ratios. These values were obtained by tensile tests and proved to be a good estimate.

Stability: Buckling can occur even within the elastic range, i. e. mostly without rupture. In fully nonlinear finite element codes like LS-DYNA, buckling phenomena are calculated by using nonlinear geometric stiffness. As a result, already deformed (buckled) areas of the model will be greatly deformed even with small extra loadings and thus will be unstable.

### 4.4 Fracture Criteria

There are numerous fracture criteria for steel plates. Within LS-DYNA materials 24 and 123 a simple algorithm depending on effective plastic strain is implemented. If the plastic strain value at the integration points of an element exceeds the defined threshold value the element is deleted. In tensile tests, a plastic strain value of about 30% can be obtained. Depending on the finite element size this value has to be adjusted. Peschmann [3] carried out tests and calculations and obtained a curve shown in figure 8 below.

To supply own failure criteria a user subroutine is attached to materials 24 and 123 but unfortunately no history variables can be defined. As a workaround a user material has to be supplied where also the element dimensions can be obtained during calculation.

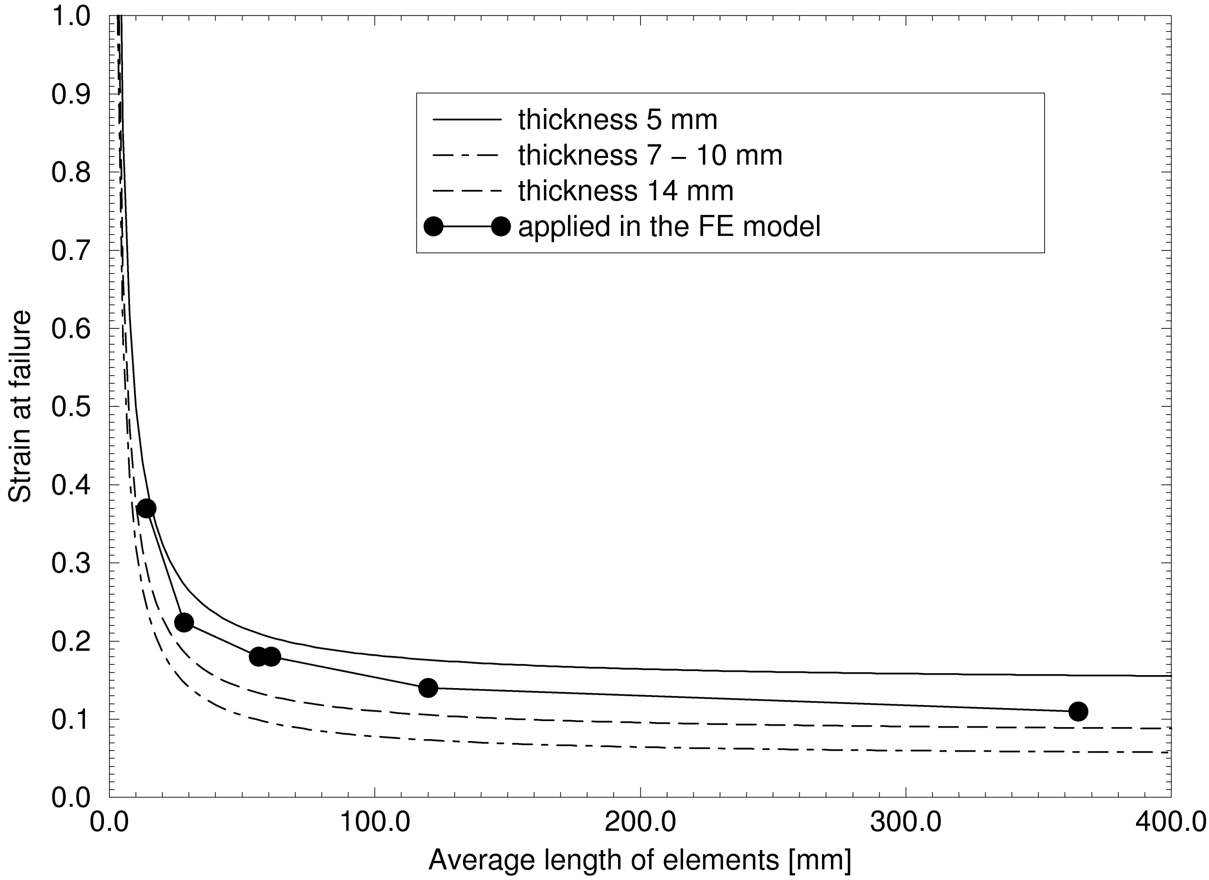


*Figure 8 strain at failure depending on side length and gage of steel plate*

## 5 Summary

LS-DYNA becomes more popular for non-automotive crashworthiness applications. Ship/offshore structure collision modeling was presented as an example for such an application.

Some issues still have to be resolved in order to make the code as easy to use as possible.

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