# "Experimental Investigation of Evacuation Systems on Passenger Ships. - Part I. Lifeboat/Davit System"

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## Abstract

The paper presents results of an experimental investigation of the launching process for a lifeboat/davit evacuation system. The objective has been to develop a methodology for testing evacuation appliances in waves, to improve the understanding of the system behaviour, influenced by waves, ship motions and their interference, as well as to obtain data about risk and effectiveness of the system. The present paper is the first part of three presenting results of an investigation of evacuation systems on passenger ferries.

The present paper has been focused on a partially enclosed lifeboat with capacity of 150 persons launched by a typical underdeck davit. The influence of parameters like wave height and period, heeling angle of the ship, davit system parameters, the side of the ship on which evacuation takes place, lowering speed and lowering procedure was studied. The estimation of the risk involved investigation of impacts with the ship, slamming against the waves and the risk of the lifeboat capsizing during the launching process. The risk assessment is based both on measurement results and video recordings. Improvements in the design of conventional lifeboat/davit systems are suggested.

## Introduction

In the management of the safety onboard a ship the decision to abandon the ship is one of the last steps to be taken. Only if an accident has happened and a chain of failures, mistakes and unlucky circumstances will turn the ship into an unsafe place, will the abandon ship operation be carried through. When all other safety measures fail, it must be possible for passengers and crew to safely leave a damaged ship even in a fairly harsh environment. The present work deals with problems concerning this last link in the safety chain, namely evacuating the passengers in rough weather.

Studying 131 incidents that took place between 1960 and 1981 with merchant vessels shows the following casualty rates (Ref.[ 1]):

- 78 % of heavy weather incidents involved loss of lives as a result of attempts to evacuate; for calm/moderate weather this number was 16 %;
- 35 % of all those attempting to evacuate in heavy weather were killed in the attempt, for calm/moderate weather this number was 5 %.

Evacuation systems in use on RoRo ferries and passenger ships are mainly designed and tested for use in calm weather situations with the ship in upright condition (Ref.[ 2]). The behaviour of these systems and the deterioration of their effectiveness with increasing wave height and the ship motions are not adequately investigated. Previous investigations of evacuation systems (lifeboats) for offshore structures have shown that rough environment and structure's motions have negative influence on the effectiveness and risks at the evacuation (Ref.[ 3] and [ 4]).

Present regulations and rules (SOLAS, Ref.[ 5]) include the tests of evacuation equipment in waves. However, these rules deal only with technical aspects. According to the LSA Code (Ref. [ 6]) each lifeboat should be subjected to impact and drop tests. This requirement is only about the lifeboat strength and does not include any requirements about the protection of passengers. IMO resolution A.689 (17) (Ref.[ 7]) requires acceleration measurements for self-righting partially enclosed lifeboats and totally enclosed lifeboats during impact tests. For open lifeboats and partially enclosed lifeboats there are no requirements about acceleration levels in either the SOLAS regulations or the IMO resolutions.

The aim of the present work was to provide a "MEP design" (EU-project "Mustering and Evacuation of Passengers", Ref.[ 8]) computer model with a database of the risks and effectiveness in connection with launching in rough weather and heeled conditions. The work was carried out through an experimental investigation at Division of Naval Architecture (KTH, Stockholm). The study also tried to find new design features to make the evacuation from a moving and heeled ship faster and safer than today.

Within this work all evacuation systems have been roughly classified in two types as "capsule" systems and "slide" systems. One standard system of each type was tested in waves and also with a heeled ship. This paper includes results of the investigation of the lifeboat/davit system. The "slide" system will be discussed in Part II.

In the present investigation attention has been focused on the study of the overall behaviour of evacuation systems and individual details have been left out. The major task in the present study has been to investigate the interaction between the evacuation system, the ship motions and the waves close to the hull. From the measured behaviour an attempt has also been made to describe the deterioration in effectiveness and risk as a function of wave height and heeling of the ship. Useful results have been obtained and suggestions for improvements of some design features and evacuation procedures are submitted.

**“Capsule” evacuation systems.**

The abandon ship process (Figure 1) for a “capsule” system can generally be described in the following five phases:

- readying equipment and passengers for launching;
- embarkation of passengers;
- descent of evacuation system;
- disconnection of rescue vehicle from the ”mother” ship;
- sail away of rescue vehicle.

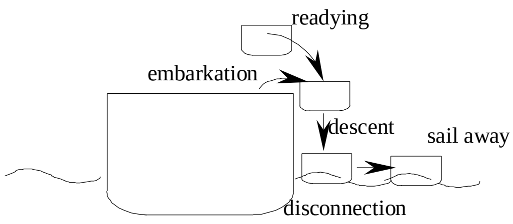


*Figure 1. Abandon ship process with “capsule” evacuation system*

In the ”capsule” systems (Figure 1) people will embark the capsule already at the muster station. The whole capsule will then be launched and disconnected from the ship in one sequence. Typical ”capsule” systems (Figure 2) are the ordinary lifeboat/davit system, the liferaft/winch system and the type of freefall lifeboat in use on many merchant ships. For the free fall lifeboats the small capacity and their placement on the ship’s stern are the most unfavourable features (Ref.[ 9]) for use on large passengers ferries.

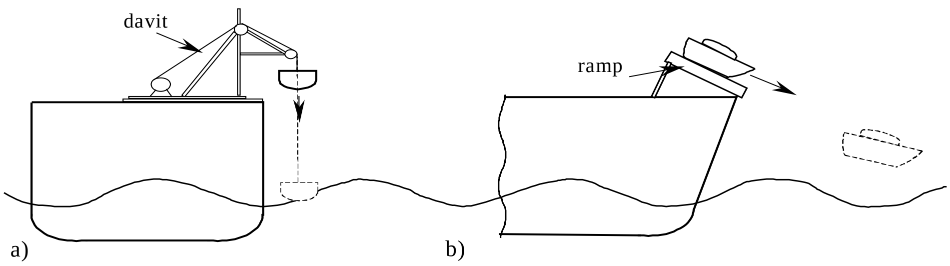


*Figure 2. The “capsule” systems: a) conventional lifeboat system, b) free fall system.*

The main advantages of an evacuation system of the capsule type are:

- possibility to protect people from harsh environment
- once in the capsule, groups can stay together in relative security under the guidance of trained seamen
- the launching sequence is of relatively short duration. The launching moment can be chosen at times when the wave heights are relatively small.

The main disadvantages of this type of systems are:

- launching of a large capsule might be dangerous in harsh weather conditions
- strict requirements on the design and operation of the launching system
- a relatively large number of well-trained seamen is required
- training in harsh conditions might be dangerous and expensive.

## Test facilities and model tests setup

The model tests have been performed in the towing tank at KTH (Ref. [ 10]). The tests have been carried out in waves corresponding to a period of 5, 6 and 8 sec and a height of 1, 2 and 3 meters in full-scale. The waves travelled in the positive x-direction (Figure 3). Both regular and irregular waves were used.

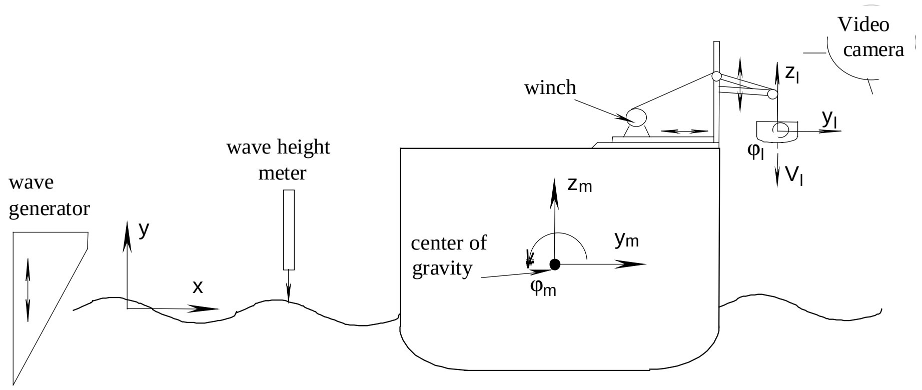


*Figure 3. Test setup.*

The aim of the present investigation was to study the behaviour of the evacuation system in the immediate vicinity of the ”mother” ship. The ”mother” ship motions and the waves' interference on the ship side are of considerable importance in these tests. The choice of scale factor in the present case was the result of a compromise, which had to be reached between a sufficient size of the model and a possibility to generate adequate waves in the towing tank. In the present work the scale factor is 40, which is sufficient to make waves with necessary height and period, and to investigate evacuation system behaviour as a whole. However, the dimensions of the evacuation systems do not allow for investigation of details in the behaviour of the system.

M/F Kronprins Frederik was taken as a prototype for the ”mother” ship model, since this ship has later been used for evacuation drill within the MEP project. Since, in the launching area the wave system can be thought of as long-crested, only the midship section has been modelled. The ”mother” ship model has a length of 2.5 m. In order to measure accelerations in $y_m$ and $z_m$-directions two accelerometers were used, and an inclinometer was used to measure the roll angle of the model.

In order to restrain the model, it was moored to bearing plates using elastic bands as shown in Figure 4. The elastic bands were used to reduce drift of the model in $y_m$-direction, in order to correlate better with the case of the full-scale ship in short-crested sea. The drift of the ship, placed in a short-crested sea, should be significantly less than in a long-crested sea. The fixing point of the elastic band was approximately in the roll centre of the model, which was assumed to be in the water level plane. The model was placed between two bearing plates, fixed on the tank walls. Free motions in $y_m$ and $z_m$-directions and free roll motion $\varphi_m$ were available by the use of free rotation balls, fixed on the model edges. The mooring has a very low stiffness and this system allowed the model to oscillate at the wave frequency and at the correct attitude to the waves, without significant restraint.

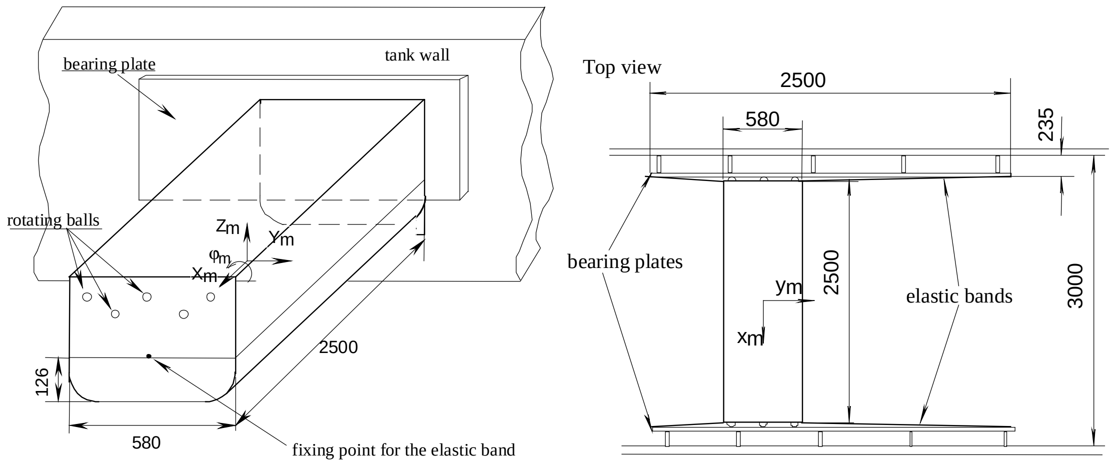


*Figure 4 The moored "mother" ship model.*

The roll resonant period of the model was obtained by a roll decay test. An agreement between the roll resonant periods for the full-scale ship and the model was accomplished by proper placing of the steel weights.

**Lifeboat/davit system models.**

Today four types of lifeboats are in use, namely: open lifeboats, partially enclosed lifeboats (PEL), self-righting partially enclosed lifeboats and totally enclosed lifeboats (TEL). On passenger ferries, in the majority of cases, open lifeboats and partially enclosed lifeboats are used. A partially enclosed lifeboat with a capacity of 150 persons, lowered vertically from winches on two cables, was chosen as prototype of the "capsule" system.

The length of the lifeboat model is 0.29 m and the beam is 0.1 m. During the tests two accelerometer transducers were used to measure vertical and lateral accelerations. Roll and pitch angles were registered by a biaxial inclinometer.

No specific davit system was modelled, but the construction of the davit model provides a possibility to change parameters such as davit arm and launching height in the parameter range necessary for this investigation (Ref.[ 10]). A servomotor used as winch enables the lowering of the lifeboat model at a velocity within the prescribed limits.

The launch height was set to 10, 13 and 16 metres in full scale. The minimum lowering speed in the tests was 0.7m/s, which was calculated according to LSA Code (Ref.[ 6]) about the lower limit of the lowering speed with the launching height of 16 m. The maximum lowering speed was set to 1.3 m/s according to practice on passenger ships.

To illustrate the influence of a horizontal distance between the ship side and the point of lifeboat suspension three values of davit arm were used in the tests: 2.5, 4 and 6 metres.

The lifeboat release mechanisms have not been modelled in the present tests, although they play a dominant role in safe launching. In most of the tests the lifeboat was lowered until the wires were loose and the lifeboat could move freely in the waves, in order to study the lifeboat motions after water entry.

## Evaluation of risk

The following risks connected with evacuation by the lifeboat/davit system were detected:

- impacts with the ”mother” ship during or after lowering due to lifeboat swing motion and/or severe wave climate close to the hull;
- capsizing of the lifeboat due to late release and/or severe wave climate close to the hull;
- potential hazard that the lifeboat will be caught on the some part of the “mother” ship due to launching on the high side and/or difficulty in sailing away.

The risk estimation is based on measurements, video recordings of the behaviour of the equipment and assumptions about human tolerance. The estimated risk, connected with evacuation, has been classified in three different categories: low, moderate and high risk (Table 1). The classification was based on acceleration limits for free fall boats (Ref.[ 7] and [ 11]), the reference tests of the lifeboat (Ref.[ 12] and [ 13]) and some assumptions about human behaviour and tolerance. Research into human injuries and behaviour is constantly in progress; when new knowledge is available the estimation of the risk can be re-evaluated.

*Table 1. Limits for risk estimation of tests of the lifeboat/davit system*

| Events connected with risk | Risk level | | |
|---|---|---|---|
| | Low | Moderate | High |
| Acceleration limits. Co-ordinate axis Y [g] | ≤6 | 6-9 | ≥9 |
| Acceleration limits. Co-ordinate axis Z [g] | ≤6 | 6-9 | ≥9 |
| Max roll angle [deg] | ≤ 30 | 30-70 | ≥ 70 |

It is assumed that the probability of human injures is about 50% for the cases with high risk, 5% for the moderate risk and 0,5% for the low risk cases.

Because the lifeboat launch starts at random time relative to the ship motions there is some uncertainty in results of lifeboat impacts and measured accelerations during launching. Due to the limited number of tests, the stochastic influence is hidden in the results. The influence of this parameter may be investigated with a simulation program. However, the conclusion in the report is based on more than 300 randomly chosen launching tests. A more thorough investigation would probably not change the main conclusion in this paper.

## Results

The tested lifeboat/davit system fulfils its functions only during gentle weather conditions. In the majority of the tests in 1m waves the risk of launching corresponds to the risk in still weather. In higher waves the risk rapidly increases (Figure 5).

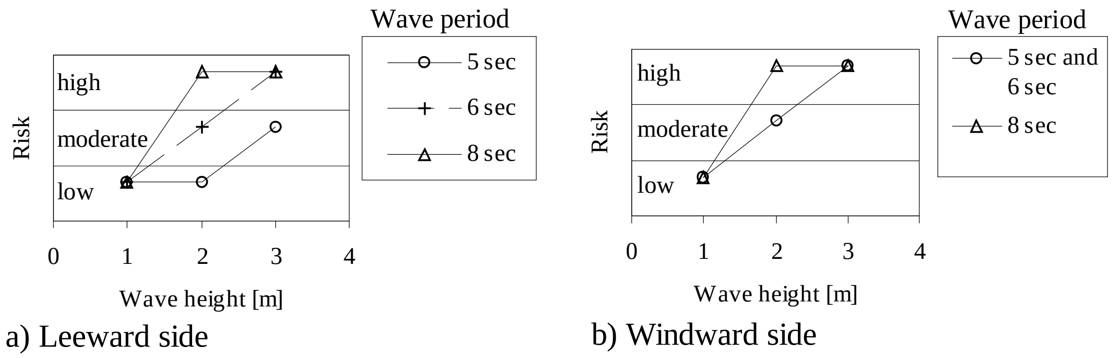


*Figure 5. Risk of evacuation by the lifeboat in waves from 16 metres launching height close to the hull.*

The waves on the leeward side of the "mother" ship are smaller than on the windward side. This means that launching on the leeward side is more favourable than on the windward side.

The risks connected to the lifeboat launching in waves with different periods depend on different factors. A general trend in the results is that the short waves cause small roll motions of the "mother" ship. They are also effectively reflected against the ship side and cause a large difference in wave climate on windward and leeward side of the ship. In short waves the risk of evacuation on the windward side is higher than on the leeward side (Figure 5). In long waves the ship motions are large and the wave reflection against the shipside is small and therefore the influence of windward/leeward side is small (Figure 5).

When launching is performed from the high side on the heeled ship, careful sliding of the lifeboat along the shipside is best suited for the launching operation. In this case the ship structure in the launching area has a large influence on the risk connected with launching. The “mother” ship construction in the launch area should not contain any construction element (fenders, openings and etc). In high waves the bilge keels may cause the lifeboat to get jammed under the heeled ship. The risk of evacuation, performed at the low side, depends on the wave climate close to the ship and increases with an increase of the wave height. Influence of windward/leeward for the heeled ship is the same as for the ship in upright condition.

The influence of the davit parameters (davit arm length, launching height and lowering speed) depends on wave period. In short waves when the ship motions are small the davit parameters have only a small effect on the risk. For the longest waves the period is close to the resonant roll period of the mother ship and the ship motions are large. The lifeboat swing motion will be large and the risk for impact against the shipside depends on davit parameters.

Figure 6 shows the influence of davit parameters on the risk of evacuation. The launching point highest and close to the hull was found to be dangerous on both leeward and windward sides. An increase in davit arm length reduces the risk of impacts against the ship and large lateral accelerations.

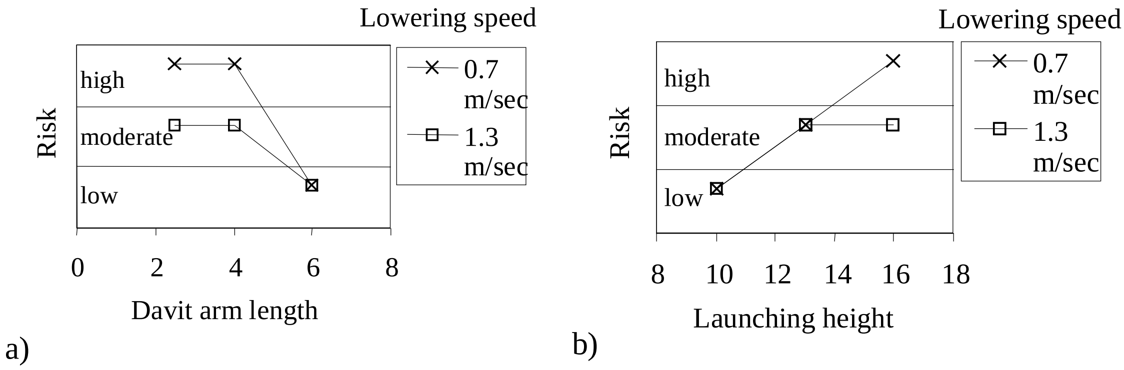


*Figure 6. Influence of a) davit arm length (launching height is 16 metres) and b) launching height (davit arm is 2.5 metres) on the risk connected with launching of the lifeboat in 2-meter waves with a period of 8 seconds on leeward side (varying lowering speed).*

A decrease in launching height reduces the risk of impact with the ship. However, when evacuating at the low side it may be impossible to use the lifeboat if it is located too close to the water. An increase of the lowering speed does reduce the swing motions of the lifeboat and thereby the risk for impacts against the ship.

A short time between water entry and disconnection is important to reduce the risk of collision with the ship or possibility of capsizing during disconnection. This is particularly important during launch on the windward side and from the damaged ship, when the risk of capsizing or landing under the ship and getting jammed there, is high.

The lifeboat system was tested in irregular waves with a significant height of 2 m and a zero down-crossing period of 6 sec. The evacuation was performed on the windward side and with the ship in upright condition. The roll angle of the ship was from 2-3 degrees up to 10 degrees, depending on the incoming wave amplitude.

All tests in irregular waves of the lifeboat system were done with a launching height of 16 m. The davit arm was 2.5 m and the lowering speed 0.7 m/sec. The wave climate was not so hard as in regular waves, since regular standing waves were not developed. The lifeboat motions in the waves and water entry are not a severe hazard to occupants. The risk during launching depends mostly on the lateral motion of the lifeboat, caused by the ”mother” ship motions. The risk of the launching was moderate in 75 % of the tests, which correlates fairly well with the result obtained for the same ship condition and davit system parameters in regular waves with a period of 6 sec and a height of 2 metres. The risk of evacuation can be reduced by choosing the launching moment when the wave heights are relatively small.

## Discussion and conclusion

The lifeboat behaviour during launching from the "mother" ship into the water was experimentally investigated. A number of key parameters, such as the ship condition, the side on which launching was performed, the davit system parameters (davit arm, launching height and lowering velocity) and the exciting waves, have been studied and their effects on lifeboat launching investigated. The estimation of risk was based on measurements of accelerations and roll angle of the lifeboat as well as video recording.

The results led to an improved understanding of the lifeboat launching operation and can be incorporated into future evacuation system design. The following suggestions of improvement for conventional lifeboat/davit system are put forward:

- improvement of lifeboat construction:
  - a change in lifeboat shape to decrease the vertical acceleration at the water entry;
  - every seat should be specially constructed to decrease the risk of human injuries during possible impacts;
  - every seat should be supplied with a seat belt, which should be used during the lowering and disconnection phases to decrease the risk of human injuries and the influence of human behaviour at large roll angles.
- possibility of increasing the lowering speed under severe environmental conditions to damp the lateral lifeboat motion;
- the lifeboat descent should be continued without stop and the lifeboat should be released from the wires immediately after or just before the lifeboat reaches the water;
- the change in davit construction for the purpose of increasing the davit arm;
- the lowering height should be about 12-14 meters to allow for launching at heeled condition.
- the ”mother” ship construction in the launching area should be free from any construction elements (openings, hooks and etc), where the lifeboat might be caught.

## References

[ 1] Pyman M.A.F. Lyon P.R., “Casualty Rates in Abandoning Ships at Sea”, Joint Meeting of The Royal Institution of Naval Architects and The nautical Institute, January, 1985.

[ 2] Captain Stephen Taylor, “A System Approach to Escape, Evacuation and Recovery”, SASMEX International ’98, Paper 6.

[ 3] Simoes Re, A., “Comparative physical model study of offshore evacuation systems”, TR-1996-24, Institute for Marine dynamics, 1996.

[ 4] Simoes Re, A. , B.Veitch, “Lifeboat Evacuation Performance in a Range of Environmental Conditions”, 2000.

[ 5] ”International convention for the SAFETY OF LIFE AT SEA”, IMO, London, 2001.

[ 6] “International Life-Saving Appliance (LSA) Code, 2001

[ 7] ”Testing of life-saving appliance”, IMO Resolution A.689(17), 1991.

[ 8] Olle Rutgersson, Elena Tsychkova, “Safety Management of the Mustering and Evacuation of Damaged Passenger Ships - MEPdesign on The Development of a Tool Box”, RINA conference “Learning from Marine Incidents”, London, October 1999.

[ 9] James K. Nelson and others, “Feasibility of Using free-Fall Lifeboats on Passenger Ship”, ICMT 95, BMT No. 31590.

[ 10] Tsychkova Elena, “Influence of Waves and Ship Motions on Safe Evacuation of Passenger Ships”, Licentiate Thesis, Stockholm, 2000.

[ 11] ”Evaluation of free-fall lifeboat launch performance”, IMO, London, 1993.

[ 12] ”Evaluation and test report for davit-launched lifeboats (TEL-60)”, Vela Luka, Croatian, shipyard ”Greben”, 1995.

[ 13] ”Evaluation and test report for davit-launched lifeboat (PEL-150)”, Vela Luka, Croatian, shipyard ”Greben”, 1997.

## Authors’ biographies

Dr Olle Rutgersson has been a Professor in Naval Architecture at KTH, Stockholm, since 1992. From 1970 to 1992 he worked with SSPA in Gothenburg, where he was involved in the testing and development of naval architectural methods and ship design.

Elena Tsychkova holds a Master degree in Hydrodynamics in 1990 from Shipbuilding University in St Petersburg, Russia and is working towards her doctorate at KTH. She has previously worked as an engineer in the field of mechanics of materials.