Use of Level Sensors in Breach Estimation for a Damaged Ship

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Abstract:
The flow of flood water from a breach in the hull into a ship is studied. The problem of estimating the size and location of the breach is discussed from the point of view of reliable flooding simulations and predictions in a real situation onboard a damaged ship. An inverse method is introduced for detecting a breach. The method is tested with a large passenger ship design by calculating a large set of randomly generated single breach damages with various combinations of sensor density, noise and filter length. The results and applicability of breach detection and flooding simulation as a part of decision support system are discussed.

Introduction

The concern for ship safety has risen as the number of passengers has increased onboard commercial vessels. The safety of passengers on a large cruise ship is a top priority. Ships have therefore become widely populated with various safety systems, namely for fire, stability, evacuation and of course flooding control. This study will focus on flooding and more specifically on breach detection. Progressive flooding in passenger vessels has been studied for several years and some very good methods have been developed during that time. However, these tools are yet to be fully utilized, especially in decision support on commercial vessels. So far *Ölcer and Majuner (2006)* have presented a method that is based on pre-calculated simulations and recently another flooding simulation tool, based on the actual initial conditions has been implemented in the Onboard-NAPA software (*The Naval Architect, 2008*).

The IMO regulations, *IMO MSC 77/4/1 (2003)*, require that all watertight spaces below the bulkhead deck should have a system to evaluate and/or quantify water ingress. Nowadays most new large passenger ships have been equipped with flooding sensors in cabin areas, machinery spaces and void spaces. A recent IMO report of a correspondence group, *IMO SLF-51/11 (2008)*, recognizes that all information used in the operational decisions should be as accurate as possible and be based upon the actual damage, flooding extent and the rate of flooding. Regarding day to day operation and decisionmaking in actual conditions, this means calculating the expected or simulated results of the flooding. In order to calculate a prediction, the initial condition, namely the location and size or area of the breach, has to be determined.

In this study the word "breach" is used to describe an opening that connects a damaged room to sea. There may be several breaches with several damaged rooms in different compartments forming one large breach but in this text the word breach is used only to mean a single opening involving one damaged room. It is assumed that if the area and location of all breaches can be calculated automatically (without human intervention) from flooding sensor output, it is then possible to calculate how the flood water will progress, thus enabling a powerful decision support system that is able to produce accurate predictions. The target of this study is to find out whether a breach can be calculated purely from the flooding sensor measurements.

The required sensor accuracy for measuring a breach was discussed in *Penttilä (2008)* and the accuracy of typical sensors was considered to be sufficient for the purpose of breach estimation. A general approach for solving the breach properties from level sensor signals was also introduced in *Penttilä (2008)*. The approach involves an inverse method for breach calculation, which is an attempt to determine the breach by matching progressive flooding simulation parameters to the measured results. The principles of this method are presented briefly. This study continues to examine the applicability of the inverse method in breach detection using a statistical set of different damages. A typical flood sensor arrangement on a large passenger ship is used and a case study of 433 random damages is used to get an approximation of the applicability of the inverse method.

Flooding Prediction Method

This study uses a time-domain flooding simulation method, described in *Ruponen (2007),* which is based on the conservation of mass and Bernoulli's equation with semi-empirical discharge coefficients for each opening. The implicit scheme ensures numerical stability even with long time steps. The simulation method has been extensively validated against experimental results. A principal assumption is that the water levels inside the vessel are flat and horizontal. This is considered to be very reasonable for passenger ships with dense non-watertight subdivision. The simulation method can also deal with air compression, but in this study it is assumed that all flooded rooms are fully ventilated.

Based on Bernoulli's theorem for an incompressible flow, the rate of flooding through an opening with an area A and discharge coefficient C_d is:

$$\frac{dV}{dt} = A \cdot C_d \cdot \text{sign}\left(H_{w,out} - H_{w,in}\right) \cdot \sqrt{2g\left|H_{w,out} - H_{w,in}\right|} \qquad (1)$$

where g is the acceleration due to gravity and H_w is the water level height. This equation forms the basis for both flooding simulation and breach detection.

Due to the inviscid nature of equation (1), Ruponen's applied method of solving progressive flooding is relatively fast and enables calculation of multiple simulations within a reasonable time with current computing power. Another advantage of this simulation method is that when the real *measured* breach is used, the results are then based on the real initial condition. This effectively eliminates the interpolation problems related to applications based on pre-calculated cases, such as *Ölcer and Majunder (2006)*. When calculation is directly based on the actual initial condition, it is not necessary to make additional assumptions regarding the routes for floodwater progression, which are required when results are interpolated within a limited set of pre-calculated results.

In Ruponen's applied method, also the leaking and collapsing of non-watertight structures, such as closed fireproof doors, are taken into account. But at the time of writing, the critical pressure heads are still based on rough estimations, presented in *IMO SLF47.INF6 (2004)*. In addition a constant discharge coefficient 0.6 is used for all openings. Within the ongoing project FLOODSTAND (see acknowledgements), comprehensive experimental and numerical studies will be carried out in order to increase the reliability of the applied parameters in the flooding simulation method. This is important also for the inverse method, because when the reliability of the simulation method is increased, consequentially as a side effect, the reliability of the inverse method is also increased.

Inverse Method for Breach Analysis

Principles

Determining the source of the flooding constitutes as an inversion problem and in this section the inverse method for breach analysis is briefly introduced. A more comprehensive description on the principles of the method is given in Penttilä (2008).The method is based on the assumption that if the hull of a ship is breached below the waterline, water starts to flood in and the flood water flows in a deterministic and usually non-reversible way. Therefore all measurable water levels inside the ship have an explicit dependency on time. The ship's floating position is also a function of time. Whatever happens is assumed to be the consequence of the breach and the breach only. This means that each breach or a set of breaches forms a unique and recognizable pattern. However the pattern is unique only in respect to the measurement accuracy. The problem is to find the right set of breaches that result in matching flooding simulation results with the observations within the measurement accuracy. In general an inverse problem is to determine the parameters that produce the known outcome. In this case the outcome is the group of measured flood water levels and the parameters are the breach set properties, like the number of damaged rooms (or the number of flood water sources), the corresponding areas of all flood water entry points and also the ship's initial loading condition. The initial loading condition is usually known due to regulations and onboard loading computers. However because of the complexity of the inverse problem, the number of flood water sources is limited in this study to a single breach.Inversion problems typically have more than one solution. The number of solutions can be reduced, by limiting the degrees-of-freedom for the breach location and changing the level of abstraction in the ship model (less detailed). The X-coordinate is ignored in this study and the Y- and Z-coordinates can be connected with the valid assumption that the breach is always located at the hull surface (Figure 1). According to *Penttilä (2008)* the Z-coordinate has the greatest significance, but only near the waterline. In this study the approximation described in *Penttilä (2008)* is used in both direct and inverse calculations and the exact location of the breach in the joint hull area (JHA) of a damaged room is not studied. At the level of abstraction of this study, the most critical task is to determine from flooding sensors which rooms are damaged. The exact location and area are secondary. The success of determining the correct damaged room depends highly on the sensor arrangement; how many, and where, the flood water sensors are installed inside the vessel. The degrees-of-freedom can be great if there is no possibility to measure the flood water in the rooms, which are primarily flooded. Such cases are more likely to fail.

If the number of different possibilities for flood water entry points can be limited, so that each combination can be calculated within a reasonable time, the breach can be solved literately by comparing the results of each possible breach to the actual measurement so that the "best-fit" results determine the breach.

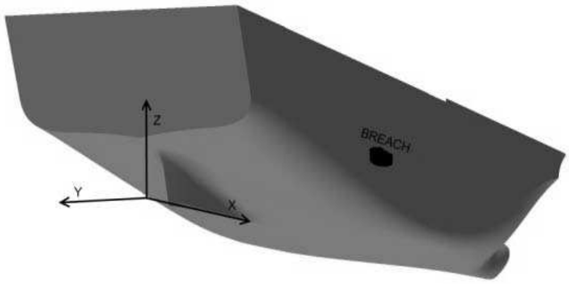


Fig. 1 Applied co-ordinate system and location of the breach

Description of the Method

In this study a number of different cases are calculated. Each case is calculated with various amounts of added random noise. The amount of noise is considered to be known. It is expected that in further studies this can be derived from the applied sensor type. In order to calculate the breach origin from level measurement a specific algorithm has been developed. This is illustrated in Figure 2. Each case contains a specific known amount of added noise and the expected correlation can be calculated from this. From the detected water levels in rooms and the known connections between watertight structures, all possible entry points for flood water are derived.

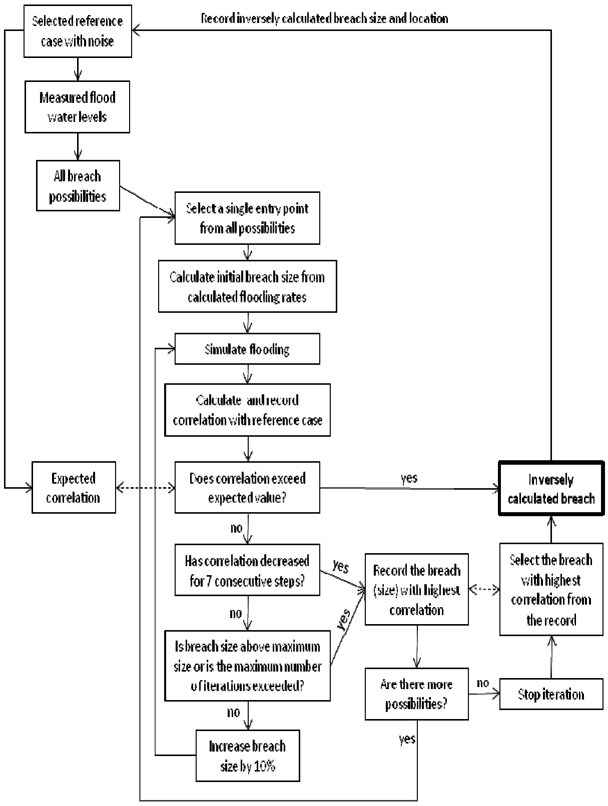


Fig. 2 Process description of the inverse iteration algorithm

The flood water can penetrate through non watertight structures and the number of different entry points can be very great. Each entry point is calculated with different breach areas from the initial area upwards in 10% increments until maximum size 2 m^2 is reached. The initial area was estimated from the flooding rates calculated from the reference data. Because the iteration works upwards from a small breach towards a larger breach size, the calculated initial size was divided by 3, to make sure the initial guess is smaller the actual size.

The iteration proceeds until the calculated correlation exceeds the expected value or until maximum number of iterations is exceeded. The expected correlation is estimated from the amount of added noise by:

$$c_{expected} = \frac{1}{\left(1 + \frac{noise}{2.5}\right)} - 0.01 \qquad (2)$$

The purpose of the expected correlation is simply to reduce the required calculation time in the iteration. The constants in equation (2) are empirical coefficients and further research is still needed.

The iteration also stops if the calculated correlation decreases for 7 consecutive steps. The correlation is calculated by comparing the relative mean difference in water levels in compartments and the relative mean differences in trim and list between the simulated results and the reference case.

After iteration of a specific breach has stopped, the next possible case is selected and the process continues until all possibilities have been calculated or until the expected correlation value is exceeded. The size and location of the breach with the highest correlation is recorded for further analysis.

Case Study

Large Passenger Ship Design

A modern Panamax size cruise ship design of 90 000 GT was used as a test case. The main dimensions of the ship are listed in Table 1.

Table 1. Case study ship data

Gross tonnage	90 000
Length over all	290 m
Breadth	32 m
Draft	7.7 m
Initial GM	2.0 m

The ship is divided into 19 watertight compartments extending to the bulkhead deck. The NAPA-model has a total of 312 openings, which connect 170 rooms. A room is always by definition watertight and water can only spread to other rooms through openings. An example of the 3D model rooms and openings is presented in Figure 3.

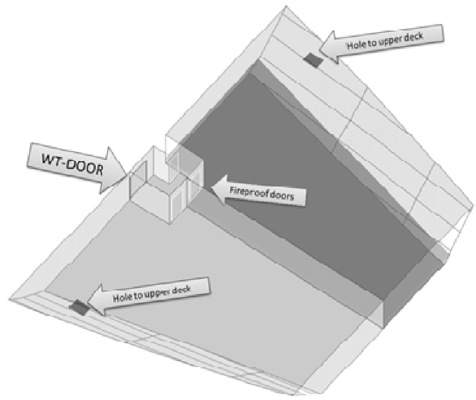


Fig. 3 Example of the 3D model and level of detail during flooding

Damage Cases

A set of 433 damage cases were generated by Monte Carlo simulation on the basis of damage statistics for collisions. However, cases with high penetration/length ratio were ignored since in those damage cases the colliding ship is likely to have a notable effect on the flooding through the breach. Each damage case was limited to a single breached room and the area of the breach was limited between 0.01 – 2.0 m^2. The limitation is necessary due to current measurement capabilities. If the breach was very large, the damaged compartments would fill with such speed that neither the selected time step for simulation nor a real flooding sensor would be able to measure the flooding rate. The applicability of the inverse method for very large breaches is not included in this study. However, in general it is considered that the damage location is easier to detect if the damage extent is large.

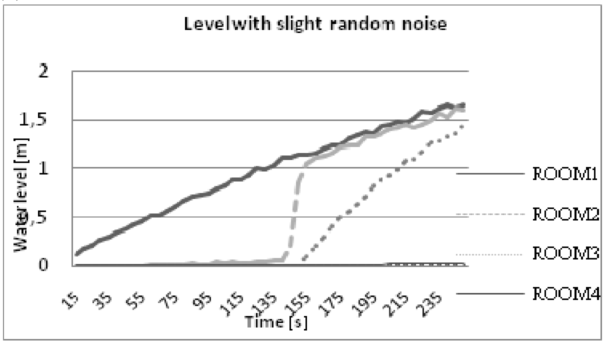
Each damage case was calculated using the NAPA software, which implements Ruponen's method (see Ruponen, 2007 and The Naval Architect, 2008), assuming a calm sea state. Total of 225 cases were calculated with all doors closed and 208 cases were calculated with all fireproof doors (total of 167) open. Most cases resulted in progressive flooding through various openings in the ship. On average 2.3 rooms were flooded during the simulation time (120 s) when all fireproof doors were closed and an average 2.7 rooms were flooded when the fireproof doors were open. All watertight openings were always defined as closed.

After each case was simulated the results were stripped in order to make the comparison for an authentic case. All data which would not be available in a real situation was removed. The available data after the stripping consists of the floating position and flood water levels in the rooms with sensors as functions of time. The entire process of testing the inverse method is illustrated in Figure 5.

Added noise in reference results

A true measurement always contains some measurement errors or noise. Possible sources for error in level measurement are discussed in *Penttilä* (*2008*). In this study two different amounts of random noise were added to the reference data. The Figures 4a and 4b illustrate the added noise to the measurement of 4 flooded rooms.

(a)



(b)

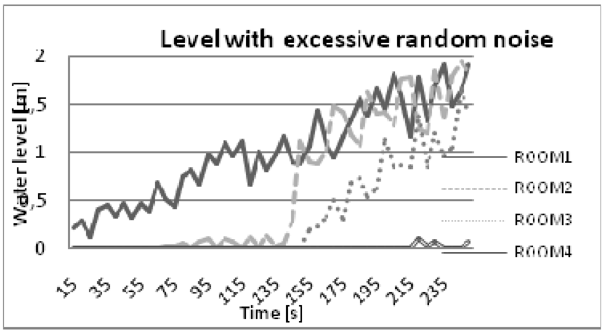


Fig. 4 (a) Level with slight added noise

The purpose of the generated random noise was to simulate disturbances in the flood water level measurements. The added noise makes it more difficult to calculate the initial flooding rate and the origin of the breach and makes the case more realistic. However, It should be noted that the added noise does not correspond to disturbances due to sloshing and is only an approximation of random measurement distubances. Typical flooding sensors described in *Penttilä* (*2008*) may also react to changes in air pressure due to flooding, but this effect is not studied in this text. All flooded spaces are assumed to be freely ventilated. The added noise is expected to decrease the likehood of determining the correct breach succesfully.

Inverse calculation

In this study the generated damage cases with various combinations of noise and time spans were fed in to an algorithm applying the inverse method to determine the location and area of the breach. The algorithm tries to determine the correct breach by iterating through different simulations and comparing the results to the available data. The available simulation data was limited to selected time spans. These time spans are referred to as "filter lengths" from the measurement analogy. The breach is being filtered from the level data. The purpose of adding noise and changing the time span of the available data was to study the effect of noise and filter length on the inverse method (discussed in *Penttilä 2008*). Same opening statuses were used in both direct and inverse calculation. The process of applying the inverse method to generated reference results is illustrated in Figure 5.

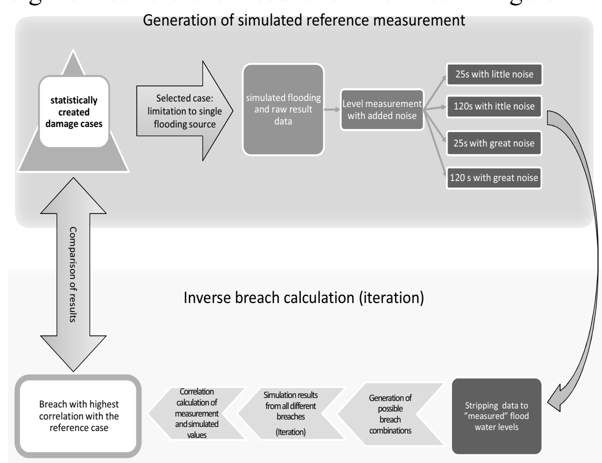


Fig. 5 Process diagram illustrating the method of testing the inverse method

The specific algorithm used in this study is optimized for a wide range of solutions and is expected to solve most cases which have a single breach solution. If the algorithm fails to produce the correct answer the reason may either be in the algorithm design or in the theoretical limitations of the method. These cases are not distinguished in this study. Research for improving the efficiency of the algorithm continues.

Inverse breach calculation is always done for a selected time span or filter length. In this study we assume that in a real damage scenario, the breach should be calculated as early as possible within the first minutes (if possible). Theoretically the inverse method is expected to determine the correct breach always if the available data is infinitely long and noiseless. However in real cases there is always some noise and the time available for measurement and calculation is limited.

The problem is similar to signal processing where a long filter is slow less susceptible to noise, whereas a short filter is fast but more sensitive to noise. The problem of breach measurement is similar to filtering also in the sense that the time span of the reference data has to be selected prior to the inverse calculation. Therefore the selected period is called in this text the *filter length*. In this study filter lengths of 25 s and 120 s are studied. These lengths fit the expected breach area (between 0.01 – 2.0 m^2). A more detailed description of the filter length selection criteria is described in *Penttilä* (*2008*). Time step used in the simulations and inverse calculation was 5 s.

Table 2. Summary of generated damage cases

	All doors closed	*Fireproof doors open*
Total number of generated damage cases	235	228
Flooding not detected by flooding sensors	11	22
Breach too small (no noticeable flooding)	70	61
Total number of remaining suitable damage cases	154	145
Average breach size	0.21 m^2	0.21 m^2
Average distance from waterline	0.98 m	1.17 m
Average number of flooded rooms (within 120 s)	2.29	2.66

Sensor arrangement

The ship is equipped with 57 flooding sensors in total of 245 rooms/tanks. 170 rooms are subject to progressive flooding and remaining 75 are closed and not connected to any other rooms by openings. There are 45 flooding sensors in the 170 rooms, of which 33 are located in rooms that are larger than 300 m^3. The "density" of the sensor arrangement in potential areas of progressive flooding is calculated by

$$\rho_{sensors} = \frac{n_{sensors}}{n_{connected\_rooms}} \tag{3}$$

In this case the density of the sensor arrangement is approximately 0.26.

The calculations were performed for two sensor arrangements. All cases were calculated first with the assumption that all rooms are equipped with a sensor (sensor density 1.0) and then with the sensor density 0.26. When each room is equipped with a sensor the success rate of calculating the correct breach is expected to be 100% and less for the case where only selected rooms are equipped with a flooding sensor.

In the case of a sparse sensor density (0.26), noise levels of 2% and 10% were considered realistic and were used in the calculation. But in the case of the high sensor density (1.0) noise levels were 5% and 35%. The higher noise levels were used because solving a breach with a very tight sensor arrangement is considered to be almost a trivial task. Therefore excessive noise was added in order to really test the method.

Results

A summary of the damage cases is presented in Table 2. Some of the generated damages resulted in too small a breach compared to the distance from the waterline. These damages did not result in noticeable flood water amounts and a total of 131 cases were left out from the inverse calculations because of this. It should be noted that with longer filter lengths also these damages could have been included. Also some damages did not result into flooding which could be detected by the flooding sensors. There were a total of 33 of these cases. It is not known whether flood water would have spread to rooms with flooding sensors if the time span had been longer. The final number of suitable cases for the inverse calculation was 299. Table 2 lists the cases in more detail.

The success rate of the inverse method was measured by checking whether the method was able to determine the correct damaged room (breach location) from detected flood water and whether the calculated breach area corresponds to the reference case within a ±30% margin. The general arrangement and the sensor arrangement of the ship model were such that in 64.6% of the cases the flood water was detected by a flooding sensor in the primarily flooded room.

Table 3 shows the results of the study for all 299 inversely calculated cases with the assumption that all rooms are equipped with a flooding sensor and Table 4 shows the results with a typical sensor arrangement of sensor density 0.26.

Table 3 Success rate of calculating the correct breach with sensor density 1

	All doors closed		*Fireproof doors open*	
	Location	Area	Location	Area
Filter 120s				
Noise 5%	99.6 %	60.7%	99.0 %	61.1%
Noise 35%	97.3 %	21.9%	98.1 %	25.0%
Filter 25s				
Noise 5%	100.0 %	68.0%	98.6 %	64.4%
Noise 35%	97.8 %	37.7%	98.1 %	41.1%

Table 4 Success rate of calculating the correct breach with a sensor density 0.26

	All doors closed		*Fireproof doors open*	
	Location	Area	Location	Area
Filter 120s				
Noise 2%	69.5%	64.5%	76.6%	65.8%
Noise 10%	67.5%	56.7%	74.5%	41.7%
Filter 25s				
Noise 2%	67.5%	31.7%	74.5%	41.7%
Noise 10%	68.2%	20.1%	70.3%	28.4%

Table 3 shows that the method used in this study is very likely to find the correct location for the breach even with high amounts of noise in the measurement data as long as each room is equipped with a sensor. The average success rate in finding the primarily flooded room was 98.6%. This is slightly less than the expected success rate of 100%. The success rate of calculating the correct breach area within the margin was more dependent on the filter length and noise than the success rate on locating the breach correctly.

Table 4 shows that the same method, when used for a sparse sensor arrangement, is less likely to find the correct breach. The average success rate in determining the primarily damaged room was 71.1%. Again the effect of noise and filter length is more noticeable for the calculation of the breach area than the location. It should be noted that the two result sets were calculated with different amounts of noise and are not directly comparable. Naturally the opening status of the fireproof doors has a greater impact on the results when the sensor arrangement is sparse. When all fireproof doors are open, the method was 8.5% more likely to determine the breach correctly.

The inverse method is based on comparing correlations of the results of different breaches to the reference results. The correlation r between the simulated and the measured levels was calculated by:

$$r = 1 - \sigma_{rel} \tag{4}$$

where σ_{rel} is mean relative deviation between measured and simulated level. Also trim and list were included in the correlation calculation.

An example of a successful case is presented in Figure 6, showing a good correlation between the results with the predicted damage size and location and the generated measurement data with very significant amount of noise.

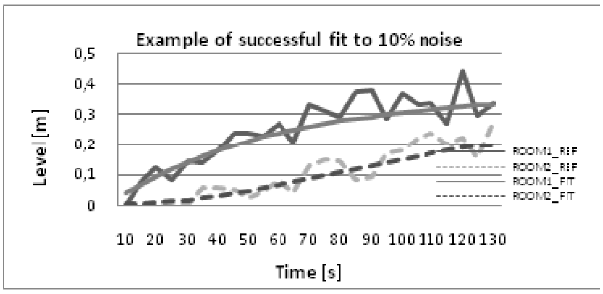


Fig. 6 Example of successful fitting of breach to level data

Also one failed case was analyzed in detail. In this case there was a breach in ROOM1 but there was an open pathway for the flood water to progress directly onto the lower deck. This case failed because there is no way to distinguish a breach in ROOM1 from a breach in ROOM2. The situation is illustrated in Figure 7.

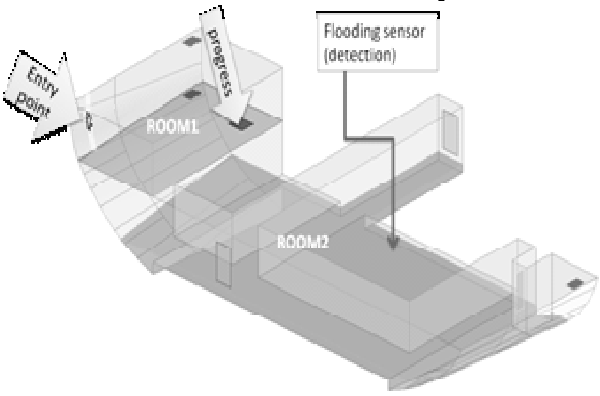


Fig. 7 Example of flooding from adjacent compartment

Flood water flows almost instantaneously through the open staircase to the lower deck and flooding remains symmetrical. There is no listing and the difference between the results of a breach in ROOM1 and ROOM2 is negligible as long as the flooding rates match. It should be noted however, that in this case, the errors in predictions due to a wrong breach location are minimal because the wrong breach produces very similar results to the correct breach. This is referred to as the "problem of similarities". Figure 8 illustrates how the fit seems to imply that the breach is correct.

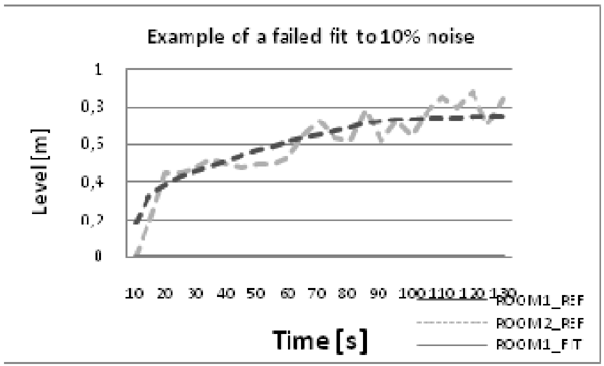


Fig. 8 Example of failed fitting of breach to level data (note the zero-level in ROOM1 in both the reference and fitted case)

Discussion

The results of the 299 inversely calculated damage cases with two different sensor arrangements strongly suggest that the inverse approach is applicable in breach detection but that the reliability of the method depends greatly on the sensor arrangement. The average likelihood of determining the breach correctly by using the inverse method was 71.1%. This is a good result compared to the sensor density of the vessel (0.26). But on the other hand the results in this study can be slightly too optimistic as such, because the number of breaches was limited to a single breach. The sensor arrangement of the vessel was considered typical.

The flooding sensor density of the ship was 0.26, which might suggest that flood water would be undetected in approx. 74% of the cases. However due to the progressive nature of flooding the flood water in most cases progressed to rooms which were equipped with flooding sensors. In 71.1% of these cases the flooding resulted in sufficiently recognizable patterns for the inverse method to work. The method resulted in almost 100% success rate when all rooms were simulated to have a flooding sensor. This does not necessarily mean that all rooms need to be equipped with flooding sensors for the inverse method to work, but it is unclear which sensors are critical. Another result is that when all fireproof doors were set open, the method more likely to find the correct breach. Fireproof doors are generally advised to be kept open during flooding in order to minimize asymmetrical flooding, but when the sensor arrangement is sparse this has also a positive effect on breach detection.

The effect of noise and filter length to the success rate is as expected. The method is more likely to find a correct solution if there is very little noise or the filter length is long. The change from little noise to excessive noise seems to decrease the success rate of finding the correct location on average by 2 percentage units. The effect of the filter length is less clear. The results would seem to indicate that 25 s filter length is in some cases not enough, but that 120 s filter length does not significantly increase the likelihood of finding the correct breach. Optimal filter length depends on the flooding rate and measurement accuracy.

The average success rate of determining the area of the breach within a reasonable margin was fairly low. On average the calculated breach size was within ±30% margin in 47% of the cases with sensor density of 1.0, and within margin in 44% of the cases with the sensor density of 0.26. Such low success rate on calculating the correct breach area indicates that the algorithm used in this study could be further developed.

Even though a more advanced algorithm is expected to increase the success rate of the inverse method, the maximum theoretical success rate is not known. It is believed by the authors that with 10% noise and 120 s filter length the theoretical maximum might be as high as 90% even with such a sparse sensor density. The example of the failed case shows that not all cases can be solved correctly even with a very dense sensor arrangement. This is because all sensors always have a specific zero-limit, which has to be exceeded before flood water is detected. If flood water does not rise up to the sensor and flows directly to another room, any method will surely fail. However if the difference in vertical location is not very great compared to the breach immersion, the actual location of a breach is not a real problem. This is because the prediction results would still remain the same. From this point of view, the results could be analyzed from the point of view of similar results and not by correct breach. The problem of similarities is however not studied in this text but it should be noted that this subject should be included in the study of optimal sensor arrangements.

The case of multiple breaches was not included in this study. Real damage situations are likely to involve multiple breaches flooding at the same time or at different times. Therefore the limitation to a single breach is a rough approximation. The problem of multiple breaches was excluded from this initial study due to the complexity. When a more advanced algorithm, able to solve multiple breaches, is developed, the same study can be repeated without the single breach limitation. It is believed by the authors that the resulting success rates would be similar or slightly less.

In this study the sensor accuracy was simulated by adding random noise to the measurement. However, real flood water sensor have another limitation, which is the minimum liquid level, that can be measured. Typical level sensors measure air pressure at 3 cm from the floor and because the air pressure in the room may change slightly there must be some zero-limit for the sensor to avoid false flooding detection. In this study the zero-limit for the sensors was 0 cm, which means that it is assumed that the sensors can measure flood water level with infinite accuracy down to 0 m. In real case the zero-limit is of order 10 cm and raising the zero-limit from 0 to 10 cm may have a decreasing effect on the success rates. However this effect was not studied in this text.

In addition to designing a suitable algorithm to solve cases with multiple breaches, another difficulty is trying to calculate the breach properties from flooding sensor output when all breaches are not yet immersed. Flooding sensors can never detect a breach, which has not yet started flooding and if there are multiple breaches, some may start to flood later on after sufficient changes in floating position. No method based on flooding sensors can solve such cases successfully with a short filter length.

Conclusions

The target of this study was to find out whether it is possible to determine the location and size of a breach purely from flooding sensor output without human intervention. A total number of 2392 cases (299 cases with two different sensor arrangements and combinations of 2 different filter lengths and 2 different amounts of random noise) were calculated inversely and the results strongly indicate that the inverse method is applicable in determining the breach from the water level data only if the sensor arrangement is dense enough. When calculated with a typical sensor arrangement, the method was able to successfully determine the correct floodwater origin in 71.1% of the cases. However the method was only able to derive the correct breach size within a reasonable margin in 44% of the cases.

It is believed by the authors that the inverse method can be developed further so that it can (if the sensor arrangement is dense enough) successfully solve a very high percentage of damage cases inversely and determine the breach size more accurately. However any method with sufficient noise will fail if the sensor arrangement is too sparse, therefore it should be noted that if a valid method can be produced, it has a theoretical maximum depending on how the flooding sensors are placed. A good method could therefore be used to study the optimal sensor placement. Well-placed sensors in a ship enable much higher precision decision support systems than what is possible today with current sensor arrangements.

An inverse method for determining the breach location and size from flooding sensor output was extensively tested. Unfortunately the results of this study are still somewhat inconclusive due to the limitation of a single flood water origin (single breach). However, so far the inverse approach in breach detection has proven to have great potential and it is believed that the general case would have similar results. Further development and testing of the presented method for the breach detection will be carried out within the FP7 Research Project FLOODSTAND.

Finally, it should be noted that even with a sophisticated breach detection analysis and carefully validated flooding simulation tools, the final outcome of any real flooding may always be different from the prediction. This is mainly because currently, the various applied parameters for openings, like collapsing pressure of a fireproof door, are not known very accurately. Furthermore, it is possible that the water will find unpredicted progression routes, such as pipes and ducts that may not be included in the simulation model. The result of any computer based decision support tool is always a prediction based on best approximations, intended to help in the decision making. The actual decision (e.g. to evacuate or to proceed to the nearest port) should always be made based on the real situation, including available support tools, visual observations and expertise of the crew and emergency response service.

Acknowledgement

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Reference:

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