SIMULATION -BASED EVACUATION ANALYSIS ON A HIGH SPEED COASTAL PASSENGER SHIP

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ABSTRACT

There have been many accidents of passenger ships on the sea and they have caused a big loss of human lives. Maritime Safety Committee(MSC) of International Maritime Organization(IMO) made evacuation analysis of Ro-Ro passenger ships mandatory in order to save as many lives as possible at the time of accident. But this is a temporary regulation and MSC/IMO tries to introduce a performance-based regulation to improve the effect of regulation. Simulation-based evacuation analysis is the basis of performance-based regulation. In this paper, we performed a simulation-based evacuation analysis on a passenger ship, which is usually used in the plying between land and islands in Korea, with EXODUS system. Through inspecting the results from this analysis in more detail, we can make a proposal to improve the safety of passenger ship. Finally we describe the features of IMEX(Intelligent Model for Extrication Simulation), a new evacuation model being developed in KRISO.

1 INTRODUCTION

In Korea, there are many sea transportation lines between land and island. Accident can occur at any time and to improve safety of public transportation, some risk assessments on ships were carried out but there has not been an evacuation analysis. Actually there was a narrow escape on January 17 2001. Democracy II, a high-speed passenger ship of 396 ton (DWT : Dead Weight), was on fire right after departure from Dae-cheong island. Fortunately, only a quarter of capacity was on the ship and they can avoid the catastrophe that might be caused by crowd. However, if the ship had been full of passengers, we could not have guaranteed this fortune.

2 IMO MSC/CIRC. 909

The MSC of IMO, at its seventy-first session on May 1999, noted that under SOLAS regulation II-2/28-1.3, Ro-Ro passenger ships constructed on or after July 1 1999 are required to undergo an evacuation analysis at an early stage of design. The MSC, noting that computerized simulation systems are still under development, decided that a simplified interim evacuation analysis method was needed and approved the "Interim guidelines for a simplified evacuation analysis on Ro-Ro passenger ships".
The purpose of the guidelines is to provide information indications on how to execute a simplified evacuation analysis and use its results to identify and eliminate, as far as practicable, congestion. It is also possible to demonstrate that escape arrangements are sufficiently flexible to provide for the possibility that certain escape routes, assembly stations, embarkation stations or life-saving appliances and arrangements may be unavailable as a result of casualty. The calculated evacuation time, as illustrated in Fig. 1, should be complied with:

$$A + T + \tfrac{2}{3}(E + L) \le 60'$$
$$E + L \le 30'$$

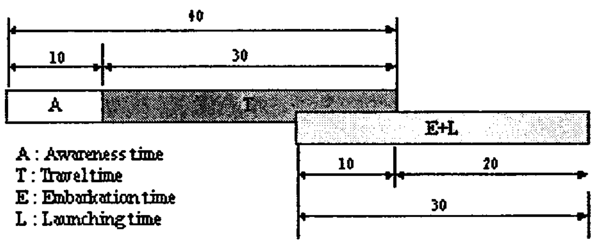

Fig. 1 Required Maximum Evacuation time by

Basically, concept of the macroscopic method is adapted in IMO MSC/Circ. 909.[1] Therefore, the regulation did not reflect human factors such age, sex and difference of personal characteristics, effects in walking speed by ship list and dynamic effect due to wave, and counter-flow because very limited data and experience were available. The IMO also recognize that these factors are very important in evacuation analysis. Therefore the IMO is concerned about a new evacuation analysis method, microscopic and simulation based method. Recently the sub-committee of IMO, fire protection, at its 45th session on January 2001, reviewed proposals relating to the development of guidance on the use of microscopic methodology for evacuation analysis [2].

3 EVACUATION MODEL

IMO MSC/Circ.909 is based on the static calculation using the main factors affecting the evacuation of the passengers in emergency. These main factors can be width of corridor, number of exit, etc. However, There are many other factors, the effects of which the static calculation cannot consider systemically. In order to overcome such limits, evacuation model can be used. It has been widely used in the design stage of ground buildings, but due to the difficulties in acquisition of necessary data and implementation for ship or naval structures, it has begun to be studied extensively only recently.

3.1 The definition of evacuation model

Evacuation model is a system or methodology to simulate and evaluate the effect of evacuation factors. Because evacuation is mainly dependent on the behaviors of evacuees, evacuation factors are those, which significantly affect the behavior of evacuees in egress situations. Evacuation factors are defined with four categories [3]. They are configuration, environment, procedures, and behavior.

The Configuration of the enclosure
This encompasses the effects on behavior of the geography of the structure, including exit widths, arrangement of exits, etc.

The Procedures implemented within the enclosure
This would include the configuration knowledge of the occupants, the training and activities of staff, and the familiarity of individual occupants with exit availability.

The Environment inside the structure
This describes the effects of heat, toxins, and smoke on the occupant's ability to navigate and make decisions.

The Behavior of the occupants
This describes the culmination of all influences, incorporating group/social affiliation, the adoption of specific roles, and the response of the individual to the emergency, likely travel speeds, and the ability of the individual to carry out desired actions.

3.2 The classification of evacuation models

Currently more than 20 evacuation models are available. It is very important to correctly recognize the philosophy and ability of model to apply an evacuation model to proper case.

Scale-based classification
In the field of pedestrian traffic modeling, models are divided into three types concerning their scales. They are microscopic, macroscopic, and mesoscopic model [4].
In microscopic models, behaviors of any single person are modeled individually. Although this requires more computing power than two other models, it is appropriate to investigate the effect of each evacuation factor. Macroscopic models are based on the similarities of pedestrian flows with liquids or gases. The basis of such a model is the continuity equation that must be supplemented by data about the relation of density and flow. Macroscopic model is the flow model advocated by the IMO Interim Guidelines and can be used for accommodation layout design purpose. Because neither of the two alone is appropriate as a generic model of evacuation analysis to account for high level and low level planning, mesoscopic models are used. Adopting mesoscopic models can solve the separation between microscopic scale and macroscopic scale, one of the biggest problems in comparing microscopic and macroscopic models via coarse graining.

Gwynne and Galea's classification
Evacuation models are divided into four types concerning nature of model application, enclosure representation, population perspectives, and behavioral perspectives [5]. Optimization, simulation, and risk assessment can be the nature of model application. Evacuation models use fine network or coarse network to represent their geometry. If the fine network is used, the entire floor space of enclosure is represented in detail usually by a collection of nodes or tiles. In the coarse network approach, only the topologies of significant structures are represented. Corridors and rooms can be examples of significant structures. The enclosure population, as with geometry, can be represented in one of two approaches: an individual or global perspective. The individual perspective approach allows for personal attributes to be assigned individually or randomly. The global perspective approach treats every population as a homogeneous group. To represent decision-making process of evacuees, evacuation models usually employ one of these five decision-making systems: no behavior system, functional analogy behavior system, implicit behavior system, rule-based behavioral system, and artificial intelligence based behavioral system.

4 EVACUATION ANALYSIS USING EXODUS

With EXODUS system, we performed evacuation analysis on a high-speed coastal passenger ship, which is a kind of

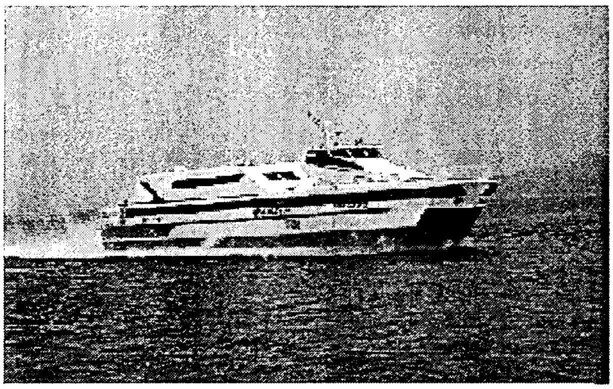

Fig. 2 A High Speed Passenger Ship : S.E.S.

S.E.S. (Surface Effect Ship) and usually used for long distance transportation.

4.1 High Speed Passenger Ship

The high speed passenger ship analyzed in this paper ship can take in 309 people including staffs and good for more than 37 knots. Its length, and breadth is 40m and 11.6m respectively and body is made of F.R.P. (Fiberglass Reinforced Plastic) There are two floors on the ship and a staircase is used when the upper floor passengers go up to take their seats. There are four main entrances and two small doors on the lower floor of ship and four emergency exits on the upper floor. Fig. 2 is the external appearance of this ship.

4.2 EXODUS

Fire Safety Engineering Group in the University of Greenwich has developed EXODUS. It is an egress model designed to simulate the evacuation of large numbers of individuals from an enclosure. Currently two types of EXODUS, airEXODUS and buildingEXODUS, are available and maritimeEXODUS is under development. EXODUS attempts to address people-to-people, people-to-environment, people-to-structure interactions during evacuation.

The EXODUS model comprises five core interacting sub-models; these are the occupant, movement, behavior, toxicity, and hazard sub-model. The software describing these sub-models is expert system based, the progressive motion and behavior of each individual being determined by a set of heuristics or rules.

The spatial and temporal dimensions within EXODUS are spanned by a two-dimensional spatial grid and a simulation clock (SC). The spatial grid maps out the geometry of the enclosure, locating exits, internal compartments, obstacles,

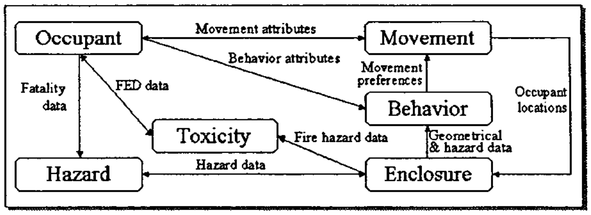

Fig. 3 Logical Interaction between Sub-models

etc. Geometries with multi-levels can be made up of multiple grids connected by stair nodes.[6]

4.3 Occupants

In EXODUS all occupants travel at their maximum run speed when unhindered and in open terrain. We set the maximum walk speed of occupant 1.5 m/s which is used as default in EXODUS. In certain places the terrain will dictate that the occupants slow down by a predetermined amount. This occurs when occupants are winding their way between obstacles such as tables and chairs within the restaurant. In this analysis, seats and staircase are acting as obstacles. The speed penalty imposed in this analysis is set at 50% of the occupants run speed.

Occupants take their seat when simulation begins and their response time is set at 0 second. This means passengers will start to evacuate right after abandonment order.

4.4 Geometries

Four kinds of geometries were generated in EXODUS according to the general arrangement of the ship. They are free space node, staircase node, seat node, and external exit Each free space node occupies 50 cm x 50 cm. Seat node

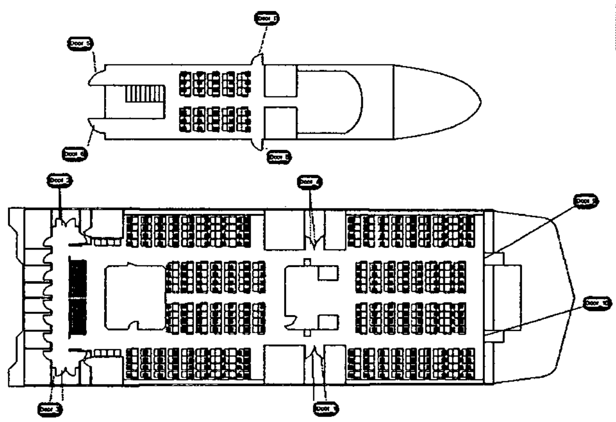

Fig. 4 Geometry Definition in EXODUS

represents and models seats. There are 294 seat nodes in total. We assumed that there is no free space node between seat nodes because it is impossible for passengers to walk at normal speed in the space between two seats. The width and drop of staircase is set at 1.2m and 3.0m respectively. When passengers use staircase, the traveling speed is decreased to 0.67m/s and 1.01m/s. The former is for going up staircase and the later is for going down. The width of external exit is 1.2m and its flow rate is set at 0.4occu/m. It can be calculated that it takes about 2.5 seconds for a passenger to pass an exit in this ship. There is some delay when a passenger move to another ship or jump off the ship. 2.5seconds reflect this delay at an exit.

4.5 Mustering & Embarkation

Evacuation from a ship consists of two phases. One is mustering and the other is embarkation because occupants who succeed in egress from the passenger quarters must take on the lifeboat for the completion of their evacuation. Usually, passengers muster at a special place where lifeboats are launched. This means that all the exits are not available and there can be a jam near the mustering place.

There is no evacuation model that explicitly supports evacuation analysis on ship. Thus these two phases, mustering and embarkation, are not provided directly and it is necessary to model them implicitly and indirectly. To do this, we can use internal exit and change the state of exits. In this simulation, there was no need to model mustering due to the type of lifeboat.

4.6 The Scenarios

In simulation-based evacuation analysis, it is very important to use proper scenarios to represent and simulate accident. We created three scenarios, one for rescue and two for escape. While scenarios for escape describe disordered and extreme progress of egress, rescue scenario does ordered and controlled transit of passengers to rescue ship.

<u>Scenario 1. Normal rescue situation</u>

If a rescue ship arrives at the site in time to rescue people from damaged ship, they usually use one of main exits or entrances. Scenario 1 assumes this situation and we can predict the amount of necessary time to transfer passengers to another ship safely. Scenario 1 describes that: 1) ship is carrying as many passengers as the seating capacity allows; 2) only one of four main entrances on the lower floor is available; 3) every passenger must wait for their turn to move to rescue ship; 4) passengers on the upper floor must come down to the lower for safe transition; 5) passengers are sitting on their seats and start to move without hesitation if transition begins.

<u>Scenario 2. Escape from undamaged ship</u>

All of the passenger ships are equipped with lifeboats to guarantee safe evacuation in any kind of emergency. They must have as many boats as they can take all the passengers on board. If there is not enough time to wait rescue ships and it is inevitable for passengers to take off the ship as soon as possible, all the entrances can be used as exits and passengers in life jacket will jump into the sea through those exits. This scenario assumes that: 1) ship is carrying as many passengers as the seating capacity allows; 2) all the exits of ship are available for evacuation; 3) it takes 30 seconds for passengers to wear their life jacket; 4) passengers start egress right after wearing life jacket.

<u>Scenario 3. Escape from damaged ship</u>

This scenario describes a usual situation of ship accident. Ship can be damaged by many factors during its navigation Fire on the ship or crash with other object can be an example of these factors. In case of this ship, some of its exits can be unavailable for egress after those accidents. If fire starts from engine room, entrances or exits close to that area cannot be used for evacuation. Furthermore, there is no distance between the bottom of main entrance and sea. This can make exits on the lower floor unavailable for evacuation. Scenario 3 describes this situation and assumes that: 1) ship is carrying as many passengers as the seating capacity allows; 2) there is a fire in engine room; 3) exits and entrances located in the rear of the ship are unavailable for egress; 4) the staircase which connects the lower and upper floor is unavailable; 5) only exits on front of the lower floor are available; 6) it takes 30 seconds for passengers to wear their life jacket; 7) passengers start egress right after wearing life jacket.

4.7 Results and Discussion

All the simulations discussed in this paper were run on a 400MHz Dual Pentium PC under the Windows 2000 environment. The estimated values from evacuation analysis are under 13 minutes in every case (Fig. 5, Fig. 6).

From scenario 1 we can predict that it will take about 750 seconds for all the passengers to take to rescue ship. There were little changes when we switched target exit in turn. There is no obstacle or structure that generates jam in the geometry so transfer time is mainly dependent on flow rate of exit, i.e. delay at the exit. Therefore switching target exit did not affect egress time.

The estimated evacuation time generated by simulation using scenario 2 is about 210 seconds. There are well-located and sufficient numbers of exits on the ship and only if they operate correctly, passengers can escape safely with wearing life jacket. Sufficient number of exits made cumulative wait time short. Their good distribution made passengers avoid jam.

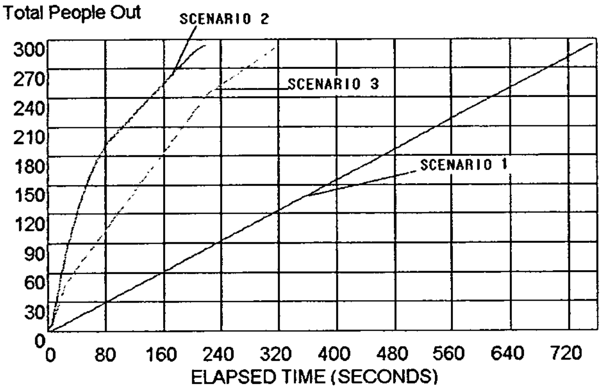

Fig. 5 Cumulative Wait Time Graph

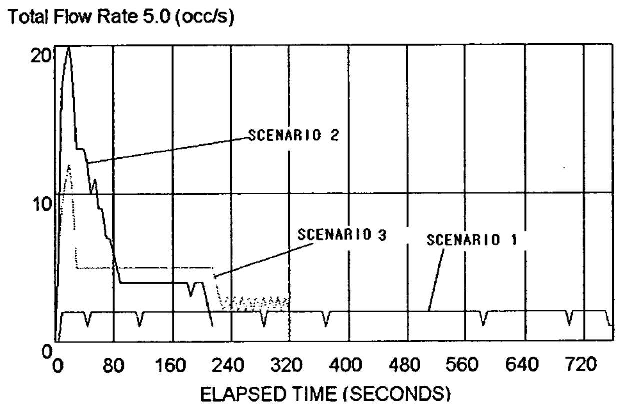

Fig. 6 Flow Rate Graph

Finally, we got about 320 second as the result of simulation using scenario 3. Fire starts usually from engine room. If the staircase, which is right above engine room, is the only way to reach the exits on the upper floor, this can make it worse for passengers to escape from passenger quarters where the air is thick with smoke. Fire rarely starts from the front of ship so two additional exits in front part of ship, which are actually used as passages to load luggage on the deck, will play an important roll in the situation like scenario 3.

5 IMEX : INTELLIGENT MODEL FOR EXTRICATION SIMULATION

The limit of previous evacuation simulations is that most of them show same results for same structures because only minimization of waiting time and optimal path selection is reflected without any regards to behavioral factors of evacuation individuals.

IMEX, Intelligent Model for EXtrication Simulation, is being developed by KRISO to overcome the limits of current models since 2000. IMEX is designed: 1) to be able to analyze a large structure including passenger ship; 2) to consider an evacuation individual's personal attributes; 3) to evaluate evacuation time and procedures. IMEX comprises two core models and one interface module, which are Spatial Model, Human Model, and Message Controller (see Fig. 7).

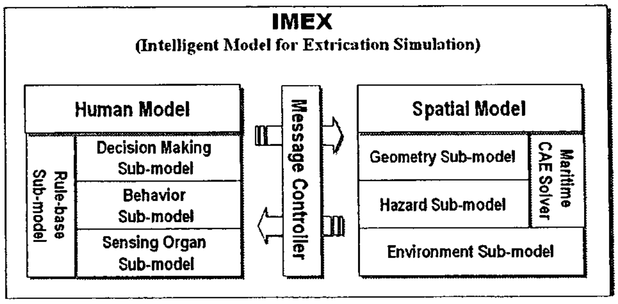

Fig. 7 System Configuration of IMEX

Spatial Model creates information and data, which can be shared among human models, and is composed of Geometry, Hazard, Environment sub-models, and Maritime CAE Solver. Geometry Sub-model transfers information regarding ship structure and equipments to evacuation individuals. In addition, Hazard Sub-model deals with information regarding fire, gas, flooding, etc, and Environment Sub-model with information regarding olfactory and audio stimuli. Maritime CAE Solver computes dynamics of ship structures by ship listing and motion.

Human Model takes actual evacuation action utilizing data and information from spatial model, and one evacuation individual constitute one Human Model. Human Model is composed of Decision Making, Behavior, Sensing Organ and Rule-base Sub-models. Decision Making Sub-model takes actual action by reflecting evacuation individual. Behavior Sub-model applies changes in mobility of evacuation individual utilizing spatial model from spatial model. Sensing Organ Sub-model can sense auditory stimuli such as alarm system, visual stimuli such as guidance, and textile and olfactory stimuli such as fire and gas. Rule-base Sub-model makes it possible to use decision-making, human behavior, and sensory data by storing them in a rule-base. Finally, Message Controller takes role of sub-layer that efficiently and correctly shares data and information between spatial model and human model. This interface module is important to compute behaviors of large population of evacuation individuals.

6 CONCLUDING REMARKS

Even though there was not a full-scale evacuation trial, we could predict necessary evacuation time that is believed to be very similar to that from full-scale trials. Advance in evacuation models made this possible. We defined three scenarios and performed evacuation analysis on a high speed coastal passenger ship, according to those scenarios with EXODUS system, one of the most popular evacuation models in the world. Although this vessel made good marks in this analysis, another analysis including fire safety and survivability assessment should be performed in more detail for assurance of public safety. To make evacuation analysis on a ship more accurate and practical, some enhancements in analysis methodology and evacuation model are required.

First, it is necessary to develop the standard scenario for evacuation analysis. In contrast with buildings, ships on the sea can generate a variety of states and conditions when an accident occurs. Using the technology of naval engineering, we can define possible ship states that would be caused by assumed damage. Developing the standard scenario for evacuation analysis on ship is one of the main research topics of IMEX team. Second, the effect of ship movement must be reflected. Ship is moving and its status is changing. Movement can affect seriously the behavior of evacuees. Third, evacuation analysis with fire analysis can magnify its usefulness. Flames and narcotic gases fire generates can take passenger's life in a very short time. And irritant gases make evacuee decide incorrectly at one of the most dangerous moments of his or her life. Through fire analysis we can get rid of potential peril before it become a reality. For fire analysis, database for materials that are usually used in ship construction, for example F.R.P., is needed. Finally, evacuation model must be able to reflect psychological effect of passengers during evacuation. For example, people have tendency to lose their reason when they encounter a life threatening peril and this can induce fatal extreme behaviors. This can be the origin of unpredictable phenomena. Even though it is very difficult to reflect these uncertain human factors in evacuation analysis, we cannot ignore them for better evacuation model and better analysis results.

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