Development of Design Support System for Safety Assessment of Ship under Damage Conditions

Soon-Sup Lee, Dongkon Lee, Ki-Sup Kim and Beom-Jin, Park, Hee-Jin Kang, Jin Choi

Maritime & Ocean Engineering Research Institute, KORDI, Daejeon, Korea

ABSTRACT

Loss of human lives and properties including environmental damage due to large scale accidents requires change of our perception to marine safety. IMO is trying to re-establish overall marine safety system through long term plan such as GBS. Along this line, current regulation based safety assessment is in process of changing into performance based methods, and for this transition, simulation based safety assessment during design stage considering damage is height necessary. In this paper, first, damage scenario is developed from of IMO regulations and accident case study. Then an integrated and simulation based safety assessment system prototype considering both damage stability and structural safety is developed for the use during ship design process.

KEYWORDS

Marine accident; Damaged ship; Safety assessment; Design support system; Design technology

INTRODUCTION

There have been many efforts centered on IMO to prevent marine accidents and save lives, property and environment from marine accidents. However, these efforts had limitations in not being able to address underlying fundamental causes.

Recently, increased emphasis on environment led many civil organizations and even governments to focus on prevention of marine accidents and protection of environment.

In addition, insurance companies having the experience of sharing substantial amount of cost due to marine accidents and damage to environment also have high interest on reinforcing safety of ships. Ship owners also view safety as not only additional cost but as a part of insurance or economical benefits. These perceptions lead to long term systematic plan for increasing ship safety such as GBS.

A current regulation on damage stability of ships does not consider actual sea conditions and also not include structural safety of damage ships. Since 2000, IMO member states proposed to consider structural safety during the damaged ship stability assessment. These proposals from European member states have also in mind to increase their competitiveness by securing related engineering technologies from previous researches.

Movements within IMO concerning major member states and technology providers will soon make simulation based safety assessments (damaged stability and structural safety) during design stage mandatory. Therefore, Korea should develop necessary technology as well as design support systems for ship designers.

In this paper, simulation based integrated damage safety assessment system prototype is developed that can evaluate damage stability and structural safety considering actual sea conditions. In order to develop the system, damage scenario is developed from studying IMO regulation and current trends, and domestic and international accident cases. The developed system is composed of subsystem such as geometric modeling, definition of damage information, structural safety assessment, and damage stability.

IMO DAMAGE SAFETY REGULATIONS

IMO damage safety regulations were first introduced in 1929 by SOLAS convention after much interest since Titanic accident. In this provision, flooded compartments are defined by factorial method and the damage stability of flooded compartments is calculated using floodable length. When large-scale accidents have occurred, related provision has been amended to prevent further accidents by IMO.

After 1987 Herald of Free Enterprise accidents, North Europe countries including UK and Norway developed collaborated researches regarding Ro-Ro passenger ships and IMO accepted SOLAS 95 amendments after Estonia accidents. At the time, Water on Deck regulation were agreed upon in Stockholm by Finland, UK, Sweden, Germany, Norway and Denmark as regional agreements, thus it is called Stockholm Agreement.

On the other hand, probabilistic approach were first proposed by professor Wendel in Hannover University in 1960s and first regulation was made in 1873 as IMO Res. A. 265. Following in suit, SOLAS II-1, Part B-1 concerning cargo ship damaged stability regulation were made in 1989 and is being enforced since 1992. Since then, SLF are working on harmonization of all damages stability related regulations in IMO based on probabilistic methods as a long term plan.

However, EU, who was the main driving force in harmonization work, stopped near the completion of preparing new regulation and propelled their own HARDER (Harmonization of Rules and Design Rationale) project, and amended SOLAS II-1 reflecting main results of the project were approved in 80th IMO Marine Safety Council to be enforced from 2009.

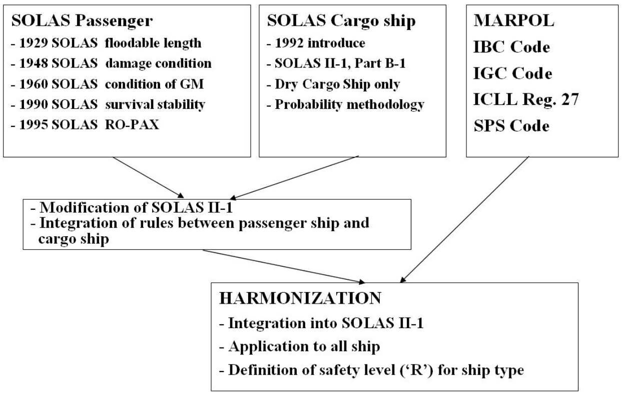


Fig. 1: Harmonization of Damage Stability Criteria

SHIP ACCIDENT CASES

A marine accident is any event associated with a marine system (vessel, terminal, port, offshore platform, etc.) that leads to adverse effects on mariners, the public, property, commerce, or the environment. A marine accident usually occurs through a chain of events ending in one or more unwanted effects. This chain of events begins with hazards capable of causing accidents. An equipment failure, human error, or external event is necessary for a hazard to cause an accident. A marine accident has at least one unwanted consequence with a measurable effect.

Many experiments and researches are being done throughout world to design safer ships with high survivability.

In this research, domestic accidents data were based on accidents data and statistics from Korea Maritime Safety Tribunal and Korea Marine Pollution Response Corporation, and international accidents data were based on marine accidents database from LMIS (Lloyd Maritime Information Service). Accident characteristics such as frequent accident vessel type, causes, impact of weather and damage amount were classified.

In addition, accidents were categorized into 10 categories: collision, grounding, flooding, engine damage, drifting, fire and explosion, loss of lives, equipment damage, loss of safe voyage and others.

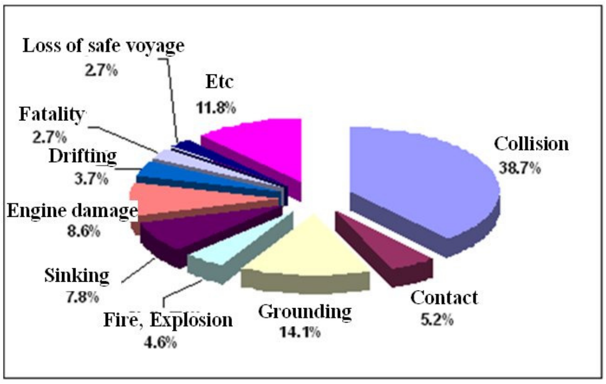


Fig. 2: The state of occurrence of marine accidents

Fig. 2 shows domestic accidents percentage for each accident category. As shown in the figure, the most frequent marine accident category was 38.7%, followed by grounding(14.1%), engine damage(8.6%), flooding(7.8%), contact 5.2%, and fire/explosion(4.6%). As for collision, grounding and contact, they are decreasing in occurrence from mid-1990s. Fire/explosion and engine damage accidents were steadily occurring. Flooding accidents were increasing in number until late 1990s, but are currently decreasing.

Fig. 3 shows the number of accidents in each category from 1990 to 2000. As shown in the figure, the accidents were rapidly increasing until mid 1990s, but are decreasing since late 1990s. Collision and grounding accidents account for more the half of total marine accidents (59.6%) followed by fire/explosion (14.1%), contact 11.3%, flooding (8.8%), and sinking.capsizing 6.3%.

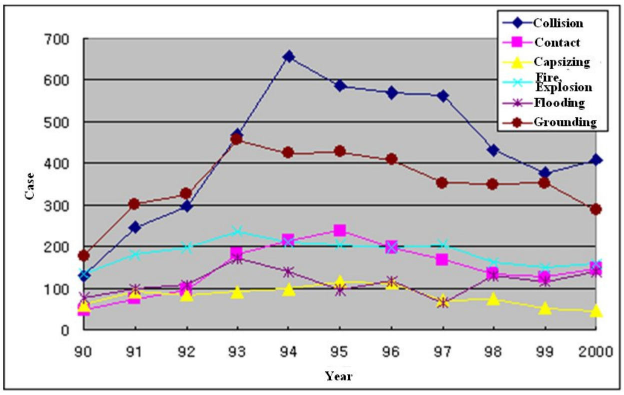


Fig. 3: the number of accidents in each category from 1990 to 2000(from abroad)

Fig. 4 shows damage depth along width of the ship in case of collision accidents based on the LMIS data, this data is used in developing damage scenario and defining damage area of the developed system.

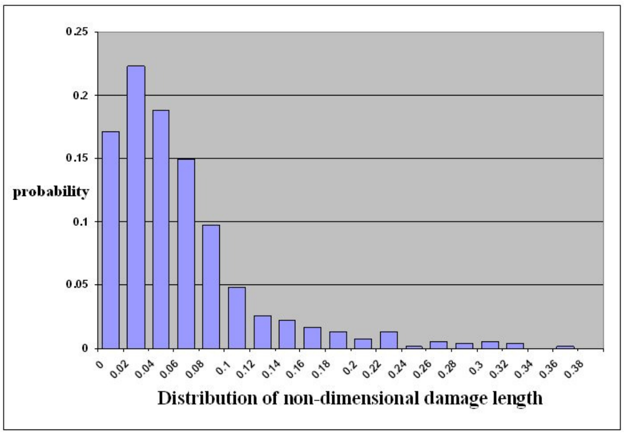


Fig. 4: Distribution of non-dimensional damage length for various length of struck vessel

DESIGN TECHNOLOGY IMPROVING DAMAGE SAFETY

Motion analysis of the damaged ship under waves

Motion analysis of the damaged ship under waves is used for predicting the probability of additional accidents such as capsizing or sinking. In case where secondary accidents are likely to occur, motion analysis will predict how long they will take to occur. Therefore, motion analysis under waves provide valuable input data for safety assessment of the damaged ship and can predict necessary data such as survival time, change in roll and trip during survival time.

In this paper, both 2D strip methods and 3D panel method are used. The strip method is used to simulation ship motion for a given period of time under the actual sea condition and the panel method is used to increase the accuracy by using 3D analysis and accounting for sloshing effects in the flooded compartments.

Probabilistic damage safety assessment method considering structural damage

This research considers damaged stability and structural safety at the same time and used survival probability calculation equation based on the probabilistic method. Damaged stability evaluates the safety considering flooding probability and survivability factor. Structural safety assessment is comprised of preliminary structural safety assessment and ultimate hull strength calculation of the damaged ship. The preliminary structural safety assessment is used in contract design stage and ultimate hull strength calculation is used in basic design stage.

Preliminary structural safety calculates a rough structural safety using required section modulus (Zreq), calculated section modulus (Zcal) and section modulus of damaged ship (Zdam) in compartment arrangement stage.

In case where structural damage is present, if Zdam value is less than Zreq, the ship is considered safe and structural damage is defined by the percentage of damage on hull bottom, side and deck. In applying this method, real ship data is used to increase the accuracy.

Ships should be designed to have sufficient strength to withstand the wave and internal load in specified damage condition such as collision, grounding or flooding. Ultimate hull strength calculations should take into account the ultimate reverse capacity of hull girder, including permanent deformation and post-buckling behaviour in structural design stage. In this paper, ultimate hull strength calculations module calculates longitudinal strength considering damaged structural members by accident and wave load. Section modulus at damaged section is calculated based on data of structural members and damaged structural elements.

Fig. 5 shows the process of preliminary safety assessment for ship. Preliminary safety assessment considers damaged stability and structural safety of ship at the same time.

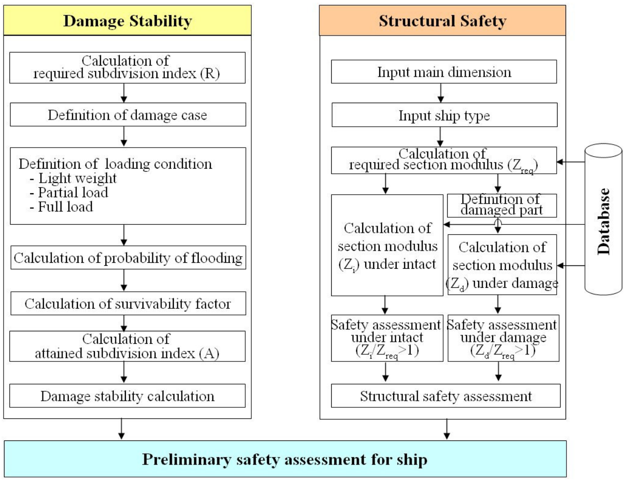


Fig. 5: Process of Preliminary safety assessment for ship

Compartment geometry modification technology

Means to improve safety are a collection of methods to improve safety that should be applied when either stability or structural safety is not up to required level, and this paper provides means to change compartment geometry. Modifying compartment geometry will reduce flooded volume and increase stability.

Means to change compartment geometry to improve stability of the ship are as follows.

- WBT width and double bottom height change
- Change location of watertight bulkhead along longitudinal direction
- Division of WBT along longitudinal direction

1) WBT width and double bottom height change

Changing WBT width is used to increase safety in case of hull side damage due to collision and changing double bottom height is used when the ship loses safety due to hull bottom damage from grounding accidents.

WBT width and double bottom height should be modified while maintaining the same cargo volume and WBT volume. When breadth of wing is increased, double bottom height will decrease, however, it is also possible to increase breadth of wing while maintaining the same double bottom height by changing landing plan of the cargo area. When WBT width and double bottom height is changed to increase WBT volume, it should be done in consideration with minimum value of WBT width and double bottom height provided by classification societies and MARPOL 73/75 13F.

2) Change location of watertight bulkhead along longitudinal direction

Accident case study indicates that collision and grounding accidents are highly likely to occur near the center of the ship.

Locating watertight bulkhead of cargo area or collision bulkhead on the location where accidents are likely to occur can be an effective strategy to increase safety. However, when cargo tank is not equally divided by moving the location of watertight bulkhead, building cost increase and decrease of productivity can happen because of increase in pump capacity and size of girders.

3) Division of WBT along longitudinal direction

When methods discussed in 4.3.1 and 4.3.2 are not enough to secure necessary damaged safety, it is required to add the number of watertight bulkheads in cargo area. It is the most effective means to increase safety, but also incur high cost of weight increase and decreased productivity.

DAMAGED SAFETY ASSESSMENT SYSTEM PROTOTYPE

This paper describes simulation based integrated damage safety assessment system prototype, which can evaluate and improve the ship's safety considering loading, sea and damage condition. The decision criteria for damage stability and structural safety are established. The subsystem of development system such as ship geometric modeler, damage stability calculation module considering wave and structural safety assessment module is developed.

Fig. 6 shows the structure of the developed system. Each of modules composing the developed system is interfaced with each other through database and graphic user interface.

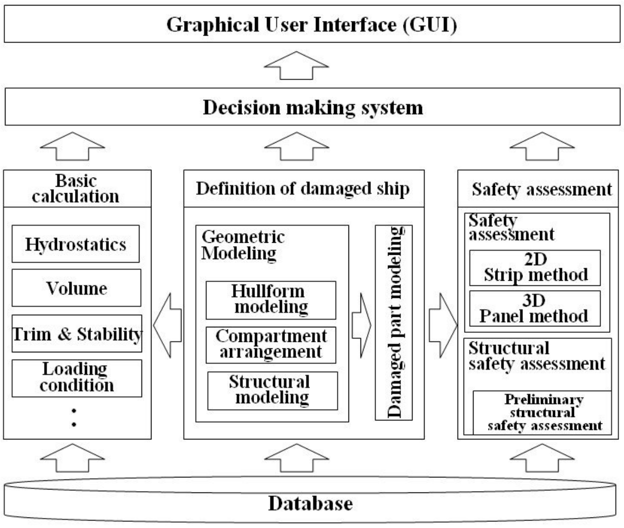


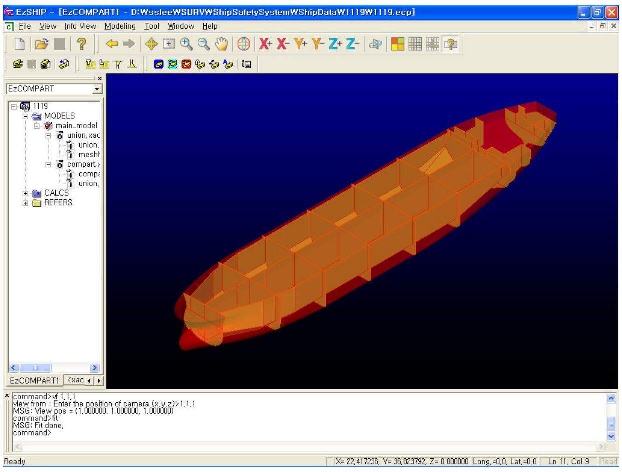
Fig. 6: System configuration

Table 1 shows development environment and tools of the prototype system.

Table 1: System environment and tools

Item	System environment and tools
Platform	PC(Pentium III and over)
Operating System	Window NT/2000, XP
Language	Visual C++, Python
Database	File System
GUI	Visual C++/MFC
Graphic Library	Visual C++/MFC, OpenGL, GLUT
Modeling System	EzHull, EzCompart
Structural analysis system	LSAP(In-house Program)
Viewer	TECPLOT, GRAPHER
Application program	In-house Program

Fig. 7 shows the results of hullform and compartment modeling of 105K tanker used to validate the system. The modeling was done using commercial CAD system in consideration with the accuracy of the model and interface with other design systems.



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command>vf 1,1,1
view from : Enter the position of camera (x,y,z)>1,1,1
MSG: View pos = (1,000000, 1,000000, 1,000000)
command>fit
MSG: Fit done.
command>
```

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Ready    X= 22,417236, Y= 36,823792, Z= 0,000000  Long.=0,0, Lat.=0,0  Ln 11, Col 9  Read
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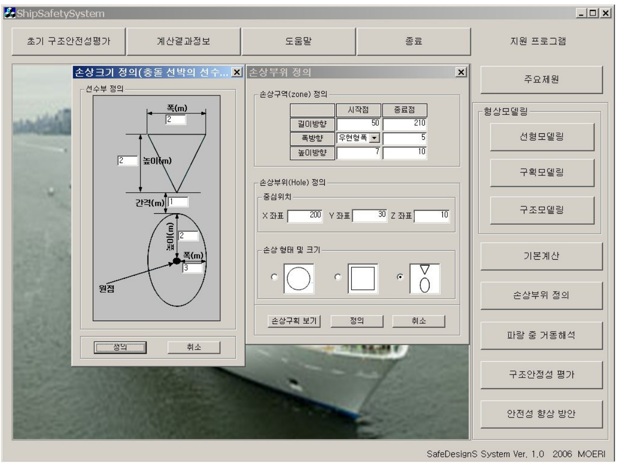
Fig. 7: 3D geometric model of damaged ship

Fig. 8 shows the process of defining damaged area, shape and size. As shown in Fig. 8, first, the user selects the damaged area of ship. Then damaged area is defined from the longitudinal, breadth and depth direction. Damaged area along width of the ship begins at the moulded width and defined inwards.

The method to define damaged area differs according to the shape, such as '○', '□' and '▯' shape.



선수부 정의: 폭(m) 2, 높이(m) 2, 간격(m) 1, 높이(m) 2, 폭(m) 3

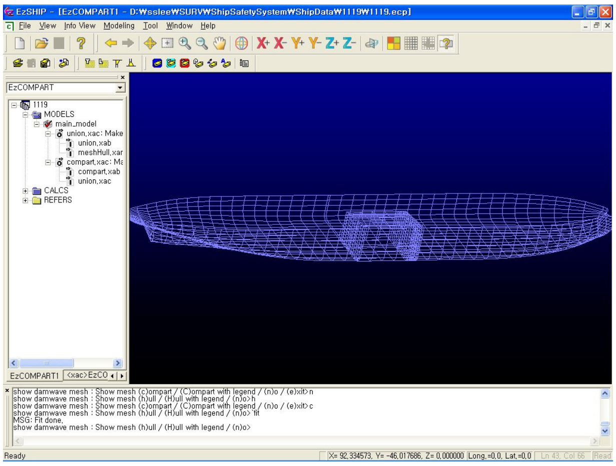
	시작점	종료점
길이방향	50	210
폭방향	우현형폭	5
높이방향	7	10

X 좌표 200 Y 좌표 30 Z 좌표 10

○ ○ ●

Fig. 8: definition of damaged area

Fig. 9 shows hullform and 3D grid of damaged compartments for the use in motion analysis under waves using 3D panel method. 3D grid is generated automatically from hullform and compartment geometric model based on principal particulars, damage information, and ship position after initial damage.



```
show damwave mesh : Show mesh (c)ompart / (C)ompart with legend / (n)o / (e)xit>n
show damwave mesh : Show mesh (h)ull / (H)ull with legend / (n)o>h
show damwave mesh : Show mesh (c)ompart / (C)ompart with legend / (n)o / (e)xit>c
show damwave mesh : Show mesh (h)ull / (H)ull with legend / (n)o>`fit
MSG: Fit done.
show damwave mesh : Show mesh (h)ull / (H)ull with legend / (n)o>
```

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Ready    X= 92,334573, Y= -46,017686, Z= 0,000000  Long.=0,0, Lat.=0,0  Ln 43, Col 66  Read
```

Fig. 9: Grid of hullform and damaged compartment

Fig. 10 shows load distribution calculated from 3D panel method: horizontal bending moment and vertical bending moment. Maximum horizontal and vertical bending moment are normally located on the center of the ship and these values are used as input data for structural safety assessment.

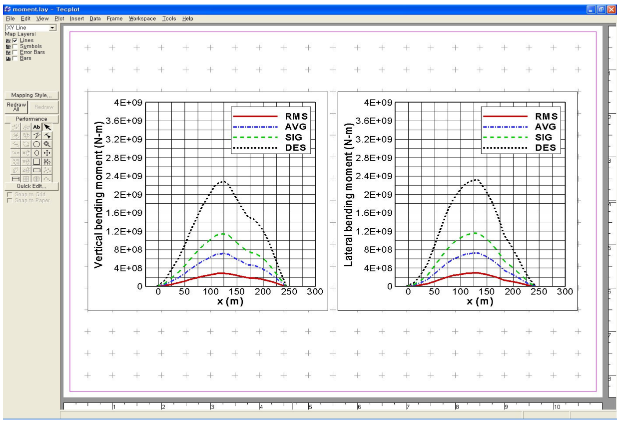
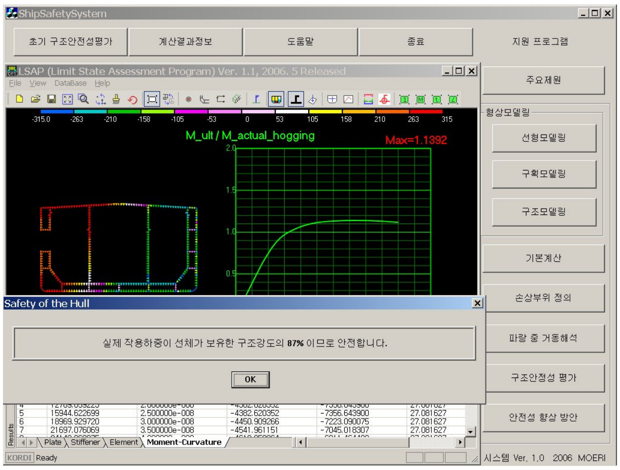


Fig. 10: Load distribution calculated from 3D panel method

Fig. 11 shows structural safety calculation results. If safety factor is 1.0 and ultimate hull strength for damaged ship is 87 percentage of residual strength, the damaged ship is safe. In the developed system, If direct load contain more than 90 percentage of ultimate hull girder strength, the damaged ship is considered to be in danger.

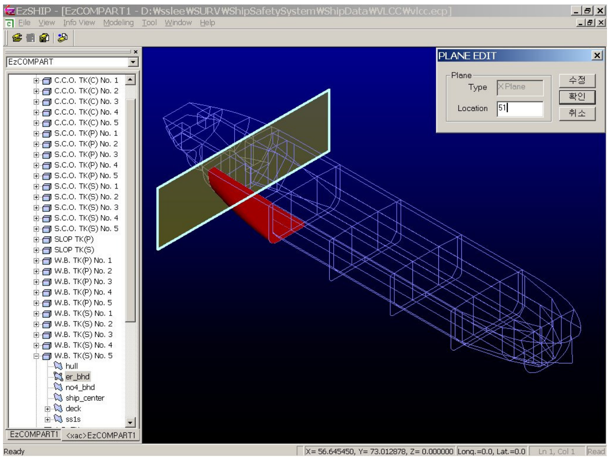
Fig. 12 shows moving the location of transverse bulkhead when modifying compartment geometry. First bulkhead to be moved is selected and new location of the bulkhead is input. When one bulkhead is moved, associated compartments are automatically modified as well.



실제 작용하중이 선체가 보유한 구조강도의 **87%** 이므로 안전합니다.

5	15944.622699	2.500000e-008	-4382.620352	-7356.643900	27.081627
6	18969.929720	3.000000e-008	-4450.909266	-7223.090075	27.081627
7	21697.076069	3.500000e-008	-4541.961151	-7045.018307	27.081627

Fig. 11: Structural safety assessment of damaged ship



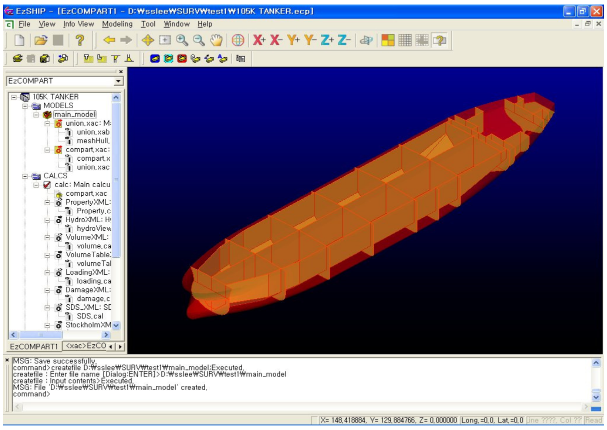
Type: XPlane
Location: 51

X= 56.645450, Y= 73.012878, Z= 0.000000 Long.=0.0, Lat.=0.0

Fig. 12: Moving the location of transverse bulkhead

Fig. 13 shows division of WBT along longitudinal direction. In the figure, No. 5 starboard WBT is divided into No. 5 and No. 6 WBT at No. 65 frame.

Fig. 14 shows the process of data input to change WBT width and double bottom height. As shown in the figure, minimum value provided from classification societies and MARPOL regulation is also shown as reference to the designer's decision, and already modeled compartments are automatically modified as well.



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MSG: Save successfully.
command>createfile D:₩sslee₩SURV₩test1₩main_model:Executed.
createfile : Enter file name [Dialog:ENTER]>D:₩sslee₩SURV₩test1₩main_model
createfile : Input contents>Executed.
MSG: File 'D:₩sslee₩SURV₩test1₩main_model' created.
command>
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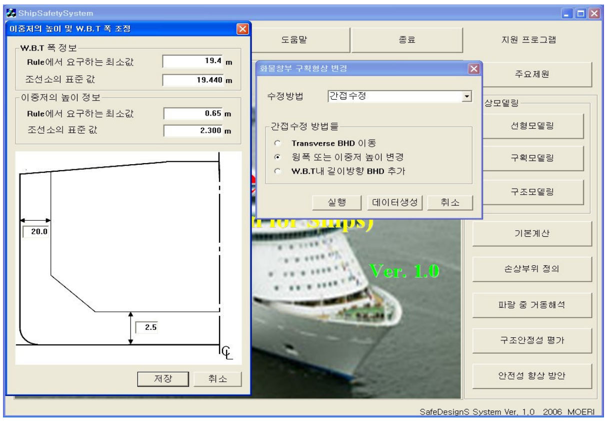
X= 148.418884, Y= 129.884766, Z= 0.000000 Long.=0.0, Lat.=0.0

Fig. 13: Division of WBT along longitudinal direction



W.B.T 폭 정보

Rule에서 요구하는 최소값: 19.4 m

조선소의 표준 값: 19.440 m

이중저의 높이 정보

Rule에서 요구하는 최소값: 0.65 m

조선소의 표준 값: 2.300 m

수정방법: 간접수정

간접수정 방법들

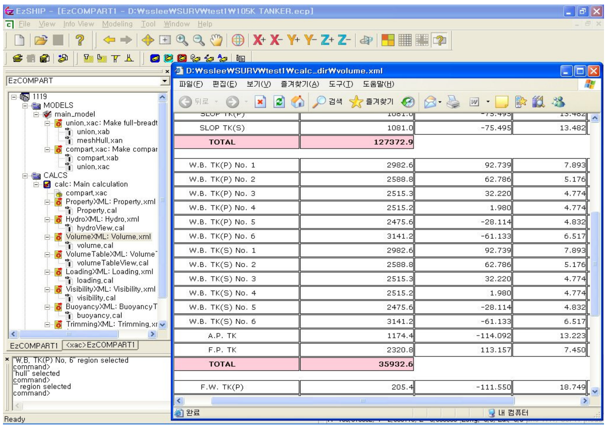
○ Transverse BHD 이동

● 윙폭 또는 이중저 높이 변경

○ W.B.T내 길이방향 BHD 추가

Fig. 14: Modification of WBT width and double bottom height

Fig. 15 shows volume calculation results of new compartment after changing WBT width and double bottom height. As shown in the figure volume is changed.



SLOP TK(S)	1081.0	-75.495	13.482
TOTAL	127372.9		
W.B. TK(P) No. 1	2982.6	92.739	7.893
W.B. TK(P) No. 2	2588.8	62.786	5.176
W.B. TK(P) No. 3	2515.3	32.220	4.774
W.B. TK(P) No. 4	2515.2	1.980	4.774
W.B. TK(P) No. 5	2475.6	-28.114	4.832
W.B. TK(P) No. 6	3141.2	-61.133	6.517
W.B. TK(S) No. 1	2982.6	92.739	7.893
W.B. TK(S) No. 2	2588.8	62.786	5.176
W.B. TK(S) No. 3	2515.3	32.220	4.774
W.B. TK(S) No. 4	2515.2	1.980	4.774
W.B. TK(S) No. 5	2475.6	-28.114	4.832
W.B. TK(S) No. 6	3141.2	-61.133	6.517
A.P. TK	1174.4	-114.092	13.223
F.P. TK	2320.8	113.157	7.450
TOTAL	35932.6		
F.W. TK(P)	205.4	-111.550	18.749

```
"W.B. TK(P) No. 6" region selected
command>
"hull" selected
command>
"" region selected
command>
```

Fig. 15: volume of new compartment after changing WBT width and double bottom height.

CONCLUSION

Marine accidents are continuously occurring despite much effort spent on preventing them, and recent accident are accompanied with devastation effects on environment as well as incurring many losses of life and property. Accordingly the rules and regulations to prevent from marine accidents are being reinforced by the international organization and national. Also, the safety is not constraints but an objective of ship design.

In this paper, a prototype system evaluating damaged ship safety considering the effect of the actual waves is developed. Damage scenarios are developed from IMO regulations and accident case study, and simulation based damaged stability and structural safety assessment system is designed. An integrated system based on ship modeler and integrating analysis module is developed.

In the future, current prototype system should be extended to reflect real design environment of industries.

ACKNOWLEDGEMENT

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