In Association with the Insignia of Doctor Honoris Causa of The University of Liège
Thursday 22nd March 2012

Recent Advances and Future Trends on Ship and Offshore Structural Design

Prof. Jeom Kee PAIK, Dr. Eng., FRINA, FSNAME
Doctor Honoris Causa of The University of Liège
President of The Ship and Offshore Research Institute
Director of The Lloyd's Register Educational Trust Research Centre of Excellence
Pusan National University, Korea

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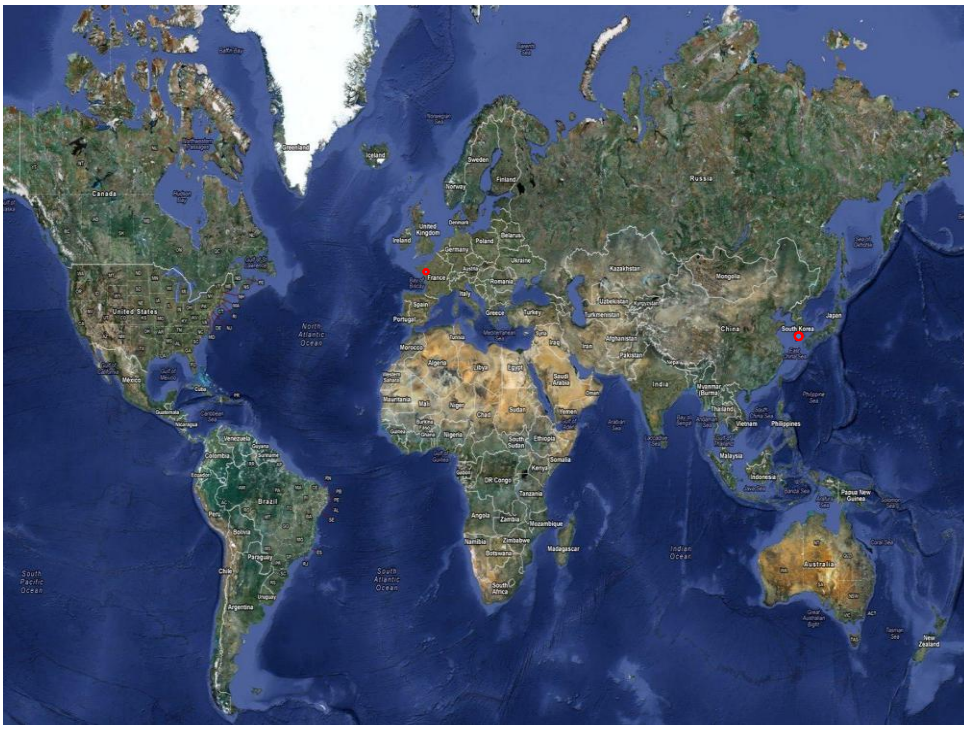

Population = approx. 50million
GNP = 20,000 USD

-Samsung Electronics
-LG
-Hyundai Motors, Kia Motors
-Hyundai Heavy Industries
-Daewoo Shipbuilding and Marine Engineering
-Samsung Heavy Industries
-STX Europe

- South Korea is the world's leading (No.1) ship manufacturer and has been consistently ranked at the top in terms of its order book and building quality and capacity.
- South Korea accounts for more than 40% of the global market for shipbuilding.
- South Korea accounts for more than 70% of the global market for offshore platform construction.

Metropolitan City of Busan, Korea

-The second largest city in South Korea
-Population = 4 million

선박 해양플랜트 기술 연구원
THE SHIP AND OFFSHORE RESEARCH INSTITUTE

DHC ULG, Prof. J.K. Paik, 22nd March 2012

www.EMSHIP.eu EMship Advanced Design

Main Campus of Pusan National University

-Total number of students = 31,000
-Total number of NAOE students = 380(undergraduates)/120(graduates)

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2. The Ship and Offshore Research Institute at Pusan National University

Organization of The KOSORI

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Research Staff (as of March 2012)

Research Staff		Number	Remark
Faculty Member		4	
Chair Professor		1	Former Deputy Minister, Ministry of Science and Technology, Korea
Visiting Professor		1	von Karman Chair Professor, University of California at Irvine, USA
Research Professor		2	
Research Engineer		6	
Graduate Student	Master	19	
	PhD	13	
Technician		1	
Administrative		3	
Total		52	

National Advisory Committee Members (as of March 2012)
- Mr. M.S. Kim, Technical Director, Lloyd's Register Asia
- Mr. J.H. Park, Senior Executive Vice President, Samsung Heavy Industries
- Mr. H.S. Bong, Senor Executive Vice President, Hanjin Heavy Industries
- Mr. T.H. Park, Senior Executive Vice President, STX Offshore and Shipbuilding
- Mr. J.S. Shin, Executive Vice President, DSME
- Mr. J.B. Park, Executive Vice President, HHI (Offshore & Engineering Division)
- Dr. K.B. Kang, Senior Vice President, POSCO

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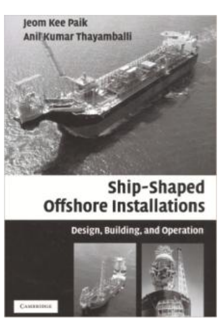
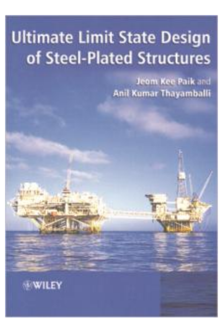
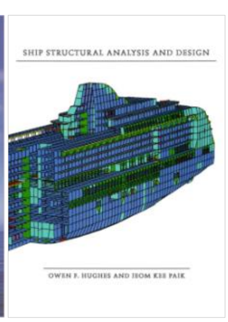
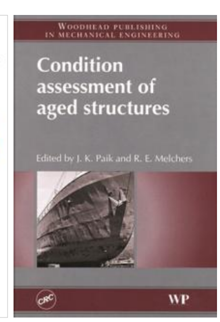
- Emeritus Prof. N. Jones, University of Liverpool, UK
- Emeritus Prof. O.F. Hughes, Virginia Tech., USA
- Prof. R.E. Melchers, University of Newcastle, Australia
- Prof. R. Snell, Oxford University, UK
- Prof. Y. Bai, Zhejiang University, China

Textbooks

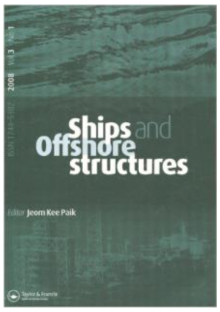


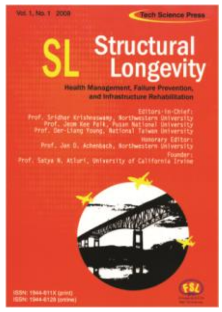






Editor-in-Chief of International Journals





Editor-in-Chief of UNESCO Encyclopedia

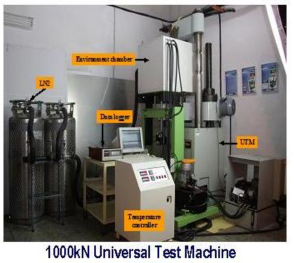
Encyclopedia Of Life Support Systems (EOLSS)
6.177 Ships and Offshore Structures
UNESCO, Paris

Editorial Board Members of International Journals

Research Facilities – Computer Program

No.	Program	Usage
1	ANSYS	Linear / nonlinear finite element analysis
2	ANSYS CFX	CFD simulations
3	LS-DYNA	Linear / nonlinear dynamic / impact nonlinear finite element analysis
4	ALPS	Ultimate strength analysis of plates, stiffened panels and hull girders
5	FLACS	CFD simulations for Dispersion and explosions
6	KFX	CFD simulations for fires
7	DNV Neptune	Risk calculations
8	CAD system	Drawing

Research Facilities – Test Facilities (1/7)



1000kN Universal Test Machine

High Speed Test Machine

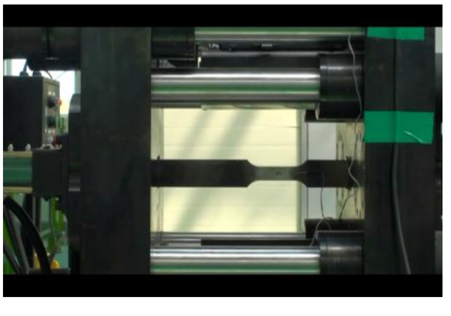
Static/Dynamic Test Frame

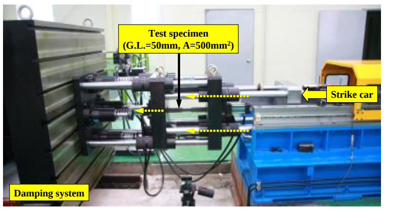
100/500kN Dynamic Actuator

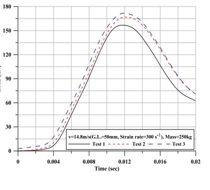
2000/5000kN Static Actuator

600bar Subsea Chamber (under Construction)

Research Facilities – Test Facilities (2/7)

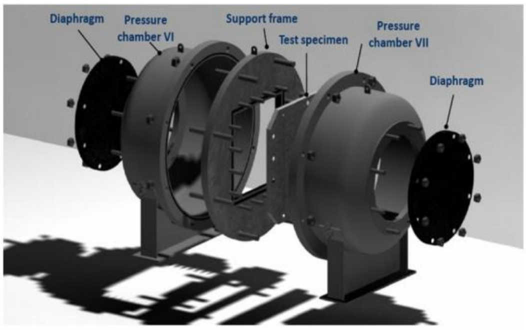




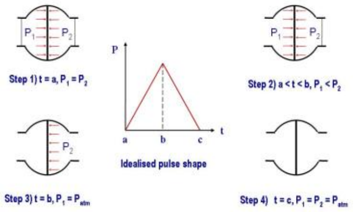


- Facility size: 15mx2mx2m
- Test model size: 1.5mx1.5mx1.0m
- Max. load, speed: 1000kN, 20m/s
- Temp.: -170~700°C
- Data acquisition: 5M/s, 16ch

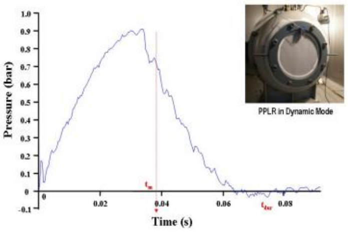
Research Facilities – Test Facilities (3/7)



Pulse Pressure Loading Rig (Univ. of Liverpool 제공)



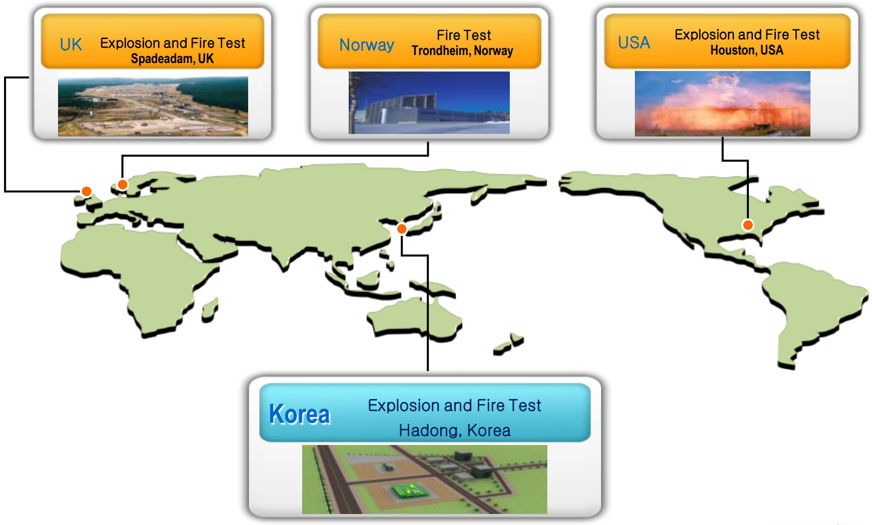
Sequence of Loading



Load Pulse Shape from PPLR

Research Facilities – Test Facilities (4/7)

Research Facilities – Test Facilities (5/7)



Research Facilities – Explosion/Fire and Subsea Test Facilities (6/7)

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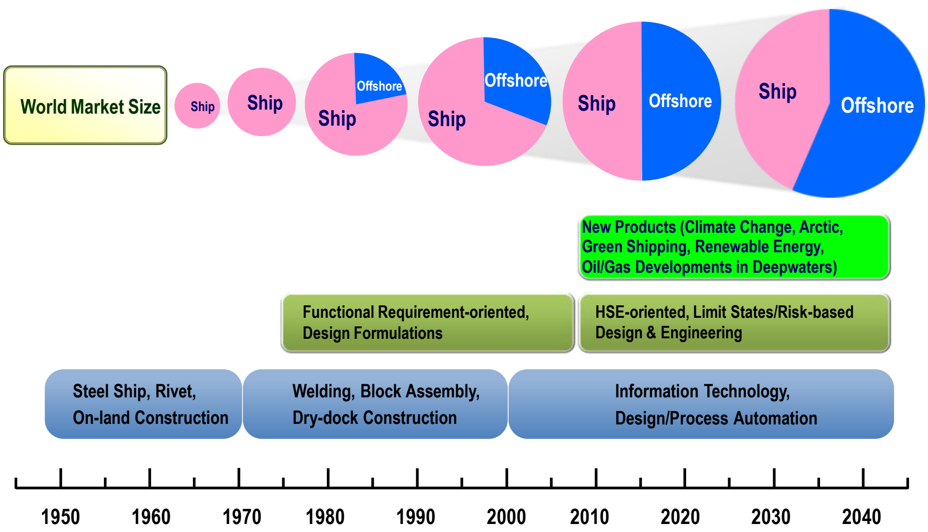
Research Facilities – Explosion/Fire and Subsea Test Facilities (7/7)

3. General Trends in Maritime Industry

Trends in Marine Technology and Industry



3. General Trends in Maritime Industry

3.1 Green Shipping

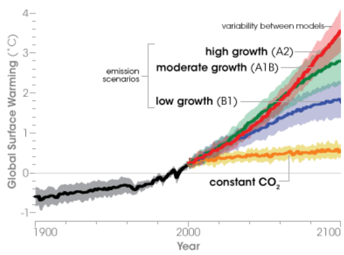
3.2 Development of Deepwaters

3.3 Human Factors Engineering

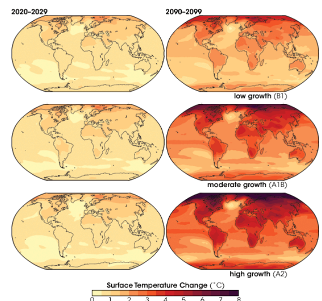
Global Warming and Climate Change

- Climate change is due to global warming.
- Global warming is due to greenhouse gases produced by human activities such as fossil fuel burning.
- 70% of greenhouse gases is CO_2 from fossil fuel.
- As long as the current CO2 emissions are uncontrolled, experts forecast that the temperature of Earth can be increased by more than 2°C until 2050 and subsequently the sea level can increase up to 10 to 20m.

Greenhouse gas emission

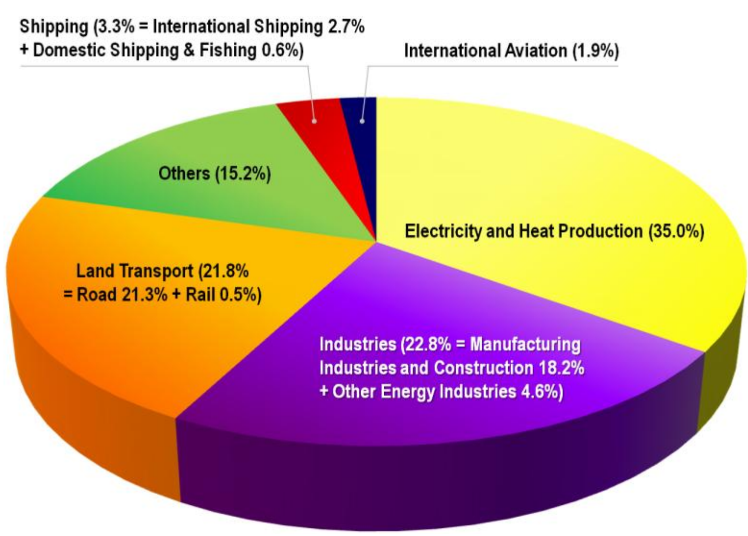


(Source: Wikipedia)



(Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007))

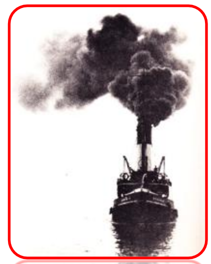
Source Breakdown of CO_2 Emissions

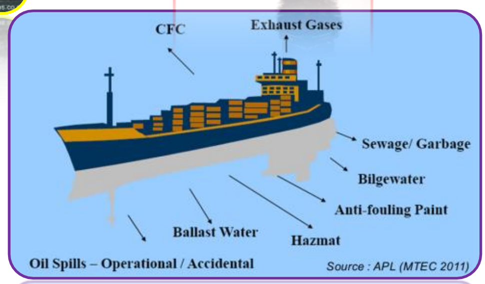


Pollution from Ships to the Environment

Air pollution on voyage	Water pollution on voyage	Ground pollution on voyage	Pollution on ship recycling
SOx	Waterproof oil	Precipitates	Paint
NOx	Bilge water	Wastes	Plastic
GHG*	Cooling water	Chemical residues	Electrical product
PM*	Grey water	Oil residues	Sealed gas
VOC*	Antifouling materials		Chemical product
	Ballast water		
	Noise		

*GHG (Green House Gas; CO_2)
*PM (Particulate Matter)
*VOC (Volatile Organic Compound)

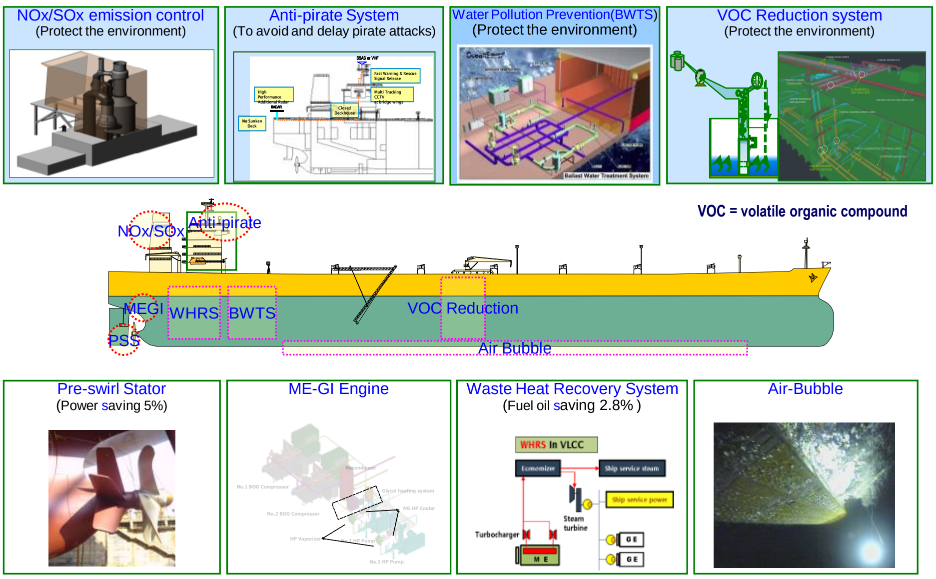




Active Methods for Reduction of CO_2 Emissions from Ships

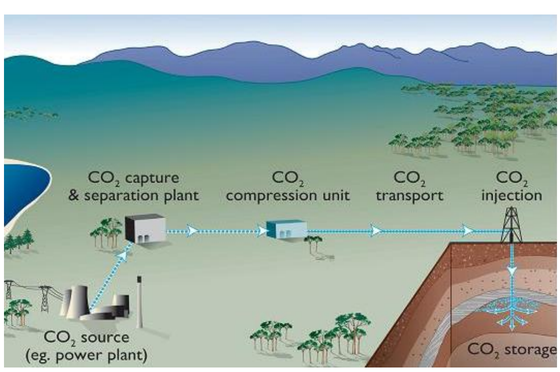
Measure	Method	How To	Reduction(%)
Active	Fuel source	▪ Natural gas ▪ Nuclear ▪ Others, e.g., solar, wind, hydrogen	20-30%
	Structural material	▪ New high tensile steel material	2-5%
	Structural design	▪ Structural optimization	2-5%
	Hull form design	▪ Hull form optimization ▪ Bulbous bow optimization	2-3%
	Propeller design	▪ High efficiency propeller	2-3%
	Device	▪ Shaft generator	1%
		▪ Pre-swirl stator (PSS)	3-6%
		▪ Water heat recovery system (WHRS)	3-4%
		▪ Air cavity system, micro bubble	7-10%
		▪ SOx/NOx reduction device	
	Operation	▪ Trim operation	3-4%
		▪ Optimum weather routing	4-5%

Active Methods for Reduction of CO_2 Emissions from Ships

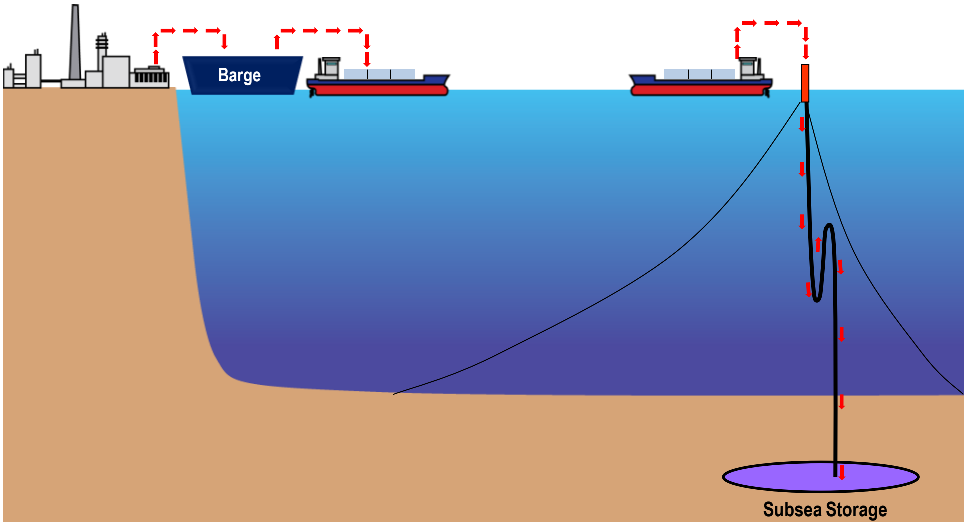


Passive Methods for Reduction of CO_2 Emissions

Measure	Method	How To
Passive	Carbon treatment	▪ Carbon capture
		▪ Carbon transportation via ship or pipeline
		▪ Carbon storage



Concept Design of CCS with CO_2 Carriers



Source: Offshore Process Eng. Lab, KAIST, Korea

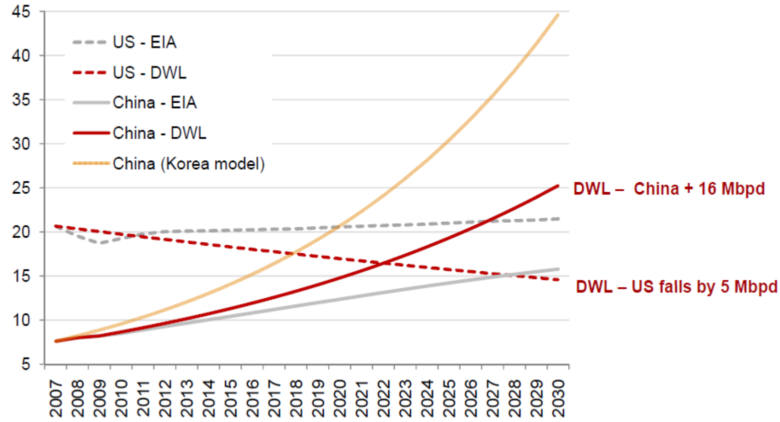
3. General Trends in Maritime Industry

3.1 Green Shipping

3.2 Development of Deepwaters

3.3 Human Factors Engineering

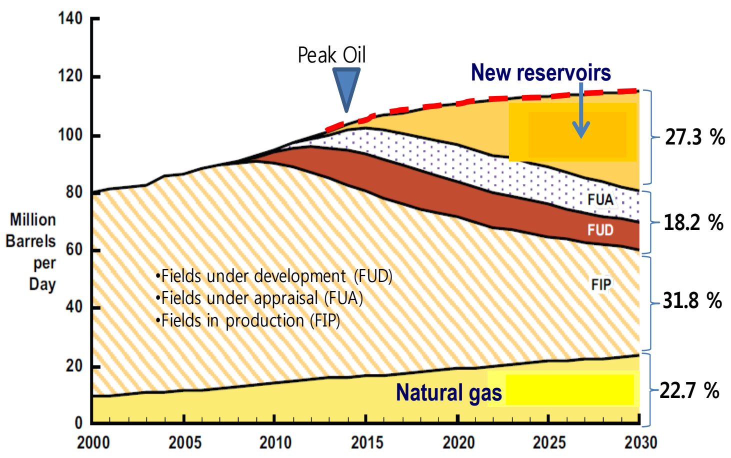
Demand of Oil in China and United States



China and US Oil Demand to 2030 – EIA & DWL
million barrels per day

Source: EIA 2010 AEO, Douglas-Westwood analysis

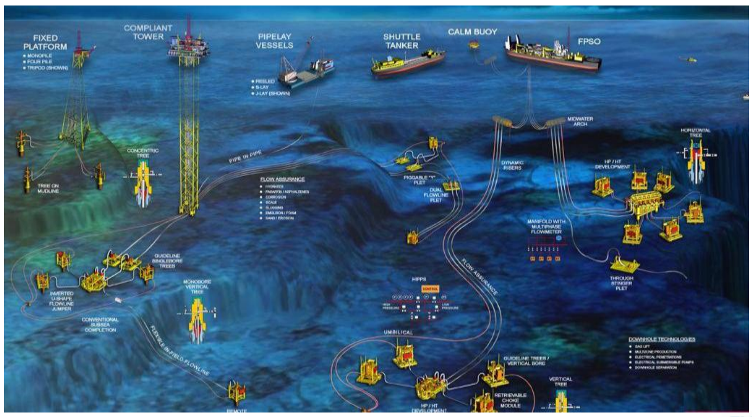
Global Oil Supplies



Source: IHS Cambridge Energy Research Associates.
90509-3

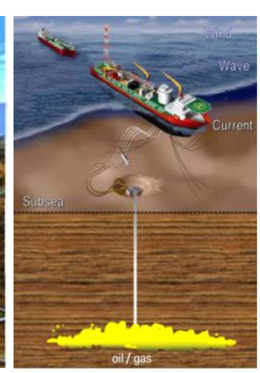
Development of Energy Sources in Deepwaters

- The deep sea is a treasure house of energy resources such as oil, natural gas, gas hydrate, minerals (rare materials).
- Renewable energy sources such as wind energy and current energy are available.
- World market size is growing with more than 500billion US$ in 2030.



Offshore Production Systems

- Fixed type in shallow waters → Floating type in deep waters
- Ship-shaped offshore unit, Semi-sub, Spar, TLP
- Pipeline infrastructure → Multiple functions such as production, storage and offloading



3. General Trends in Maritime Industry

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Most of accidents are the result of a long chain of human error, with such error responsible for
- 65% of all airline accidents,
- 80% of all maritime casualties,
- 90% of all automobile accidents, and
- 90% of all nuclear facility emergencies.

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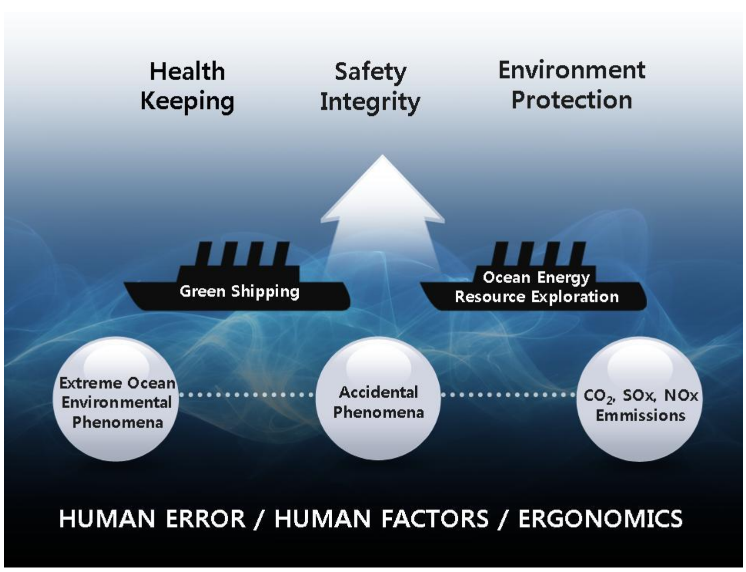
Accidents – Result of a Long Chain of Human Error

- Human error results from ignoring human factors and ergonomics.
- Ignorance of human factors is either the root cause of or a major contributing factor to many maritime accidents.
- Ignorance of engineering factors is primarily due to a lack of knowledge and guidance at the design, building and operation stages.



Importance of Human Error Minimization to Protect Human Health and the Environment and Ensure Safety

Paradigm Change in Engineering and Design

Various Types of Phenomena

Traditional

- Design Formula
- Past Experience
- Deterministic
- Allowable Stress

Future

- Engineering
- First Principles
- Probabilistic
- Limit States/Risk

Mathematical Algorithm

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\phi\alpha\beta\gamma \lim_{x\to\infty}\frac{\zeta}{\sqrt{x^2-\varepsilon x+\eta}}\frac{n!}{r!(n-r)!}$$

Experimental Investigation

International Rules and Standards

HSE & E – Health, Safety, Environment & Ergonomics

IACS	IMO	ISO
CSR/H-CSR	GBS	ISO 18072

Advanced Technologies

- First-Principles-Based Direct Methods
- Limit States-Based Methods
- Risk-Based Methods

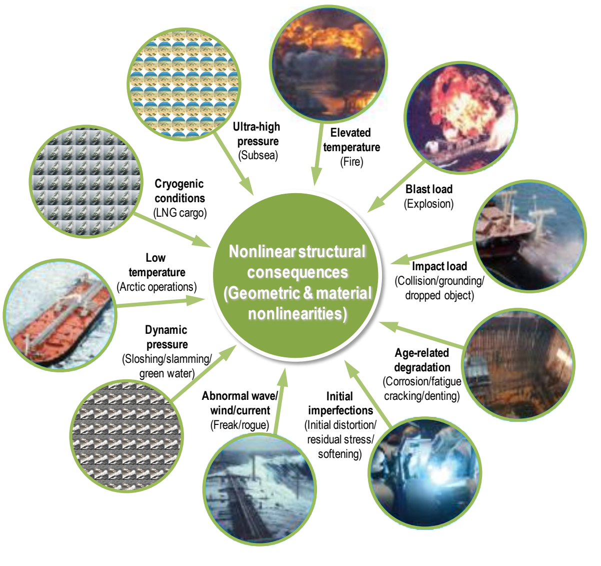
Human Factors Engineering

- Over the last decade, the likelihood and consequences of marine casualties have certainly declined, in part due to technological improvements.
- However, the public's growing concerns and intolerance for safety, health and environmental risk suggest that more has to be done going forward.
- Because the majority of marine casualties is related to human error and human factors, human factors engineering will play a central role to achieve substantive technological improvements and subsequently to prevent accidents.

April 2012 Issue of Marine Technology, SNAME

4. Ship and Offshore Structural Design: Recent Advances and Future Trends

Ocean Environmental Phenomena in Ships and Offshore Installations



Basis of Acceptance Criteria:

- Limit States: Extreme phenomena
- Reliability
- Risk: Accidental phenomena, e.g., explosion, fire

Nonlinear Structural Consequences = function of (*a,b,c,d,e,f,g,h*)

where,
a = geometric properties
b = material properties
c = fabrication related initial imperfections
d = load types/components (quasi-static)
e = strain rate effect associated with dynamic/impact load profiles due to sloshing/slamming/green water, explosion, collision, grounding
f = effect of temperatures, e.g. low (Arctic), cryogenic (LNG) and elevated (fire)
g = age-related degradation, e.g. corrosion, fatigue crack, denting

Design Criteria

$C_d > D_d$

Reliability = $\beta = 1\text{-}P_f \geq \beta_o$

Risk $\leq$ ALARP

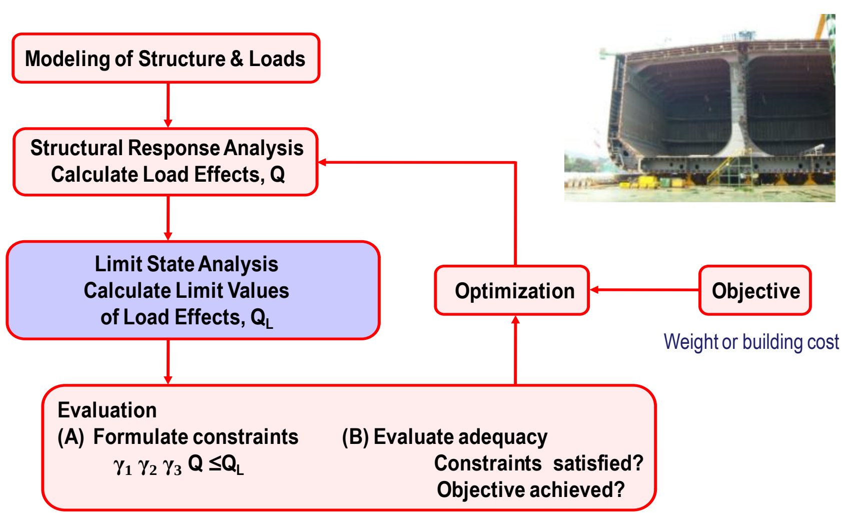
where,
C_d = Design capacity
D_d = Design demand
P_f = Probability of failure
β = Reliability index
β_o = Target reliability index
ALARP = As low as reasonably practicable

4. Ship and Offshore Structural Design: Recent Advances and Future Trends

4.1 Limit States Based Methods

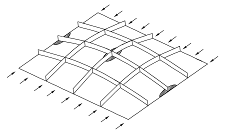
- Ultimate limit states (ULS)
- Serviceability limit states (SLS)
- Fatigue limit states (FLS)
- Accidental limit states (ALS)

Limit States Based Structural Design Optimization

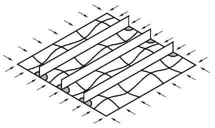


Ultimate Strength of Stiffened Panels: 6 Types of Collapse Modes

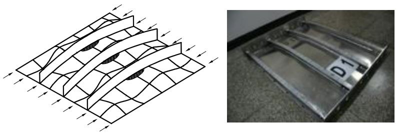
$\sigma_u = \min.(\sigma_u^{I}, \sigma_u^{II}, \sigma_u^{III}, \sigma_u^{IV}, \sigma_u^{V}, \sigma_u^{VI})$



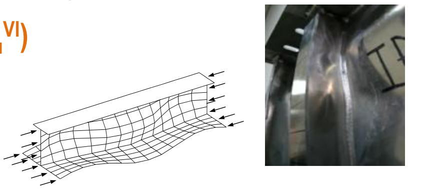
Mode I – overall collapse



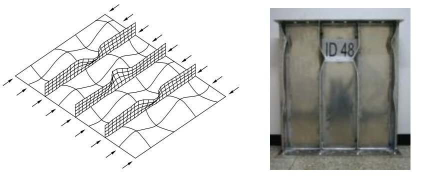
Mode II – plate-induced collapse



Mode III – stiffener-induced collapse by beam-column type collapse



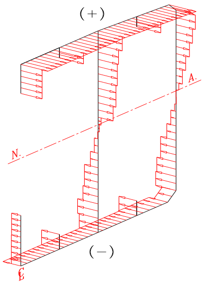
Mode IV – stiffener-induced collapse by web buckling

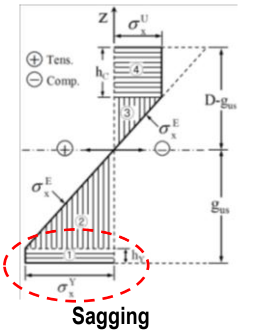


Mode V – stiffener-induced collapse by tripping

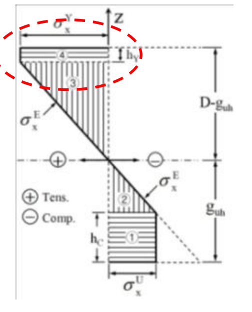
Mode VI: Gross yielding

Modified Paik-Mansour Formula for Hull Collapse Strength Calculation





Sagging



Hogging

$$\int \sigma_x dA = 0$$

$$g_u = \frac{\sum_{i=1}^{n} |\sigma_{xi}| a_i z_i}{\sum_{i=1}^{n} |\sigma_{xi}| a_i}$$

$$M_u^v = \sum_{i=1}^{n} \sigma_{xi} a_i (z_i - g_u)$$

[Ref.] J.K. Paik, D.K. Kim, D.H. Park, H.B. Kim, A.E. Mansour and J.B. Caldwell, Modified Paik-Mansour formula for ultimate strength calculations of ship hulls, accepted for publication in Ships and Offshore Structures, 2012.

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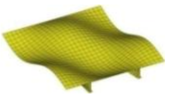
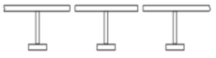
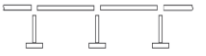
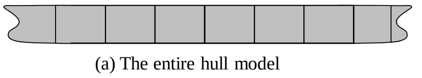
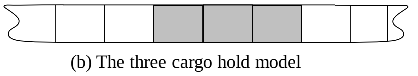
Methods for Progressive Hull Collapse Analysis

Method	NLFEM	ISUM/Smith Method	ISFEM (ALPS/HULL)
Geometric modeling		 Plate-stiffener combination model	 Plate-stiffener separation model
Formulation technique	Numerical formulation $\sigma = \int [B]^T [D][B] dvol$ [D]: Numerical formulation	Closed form formulation $\sigma = \Phi \sigma_Y$ $\Phi = edge\ function = \begin{cases} -1 & for\ \varepsilon < -1 \\ \varepsilon & for\ -1 < \varepsilon < 1 \\ 1 & for\ \varepsilon > 1 \end{cases}$	Numerical formulation $\sigma = \int [B]^T [D][B] dvol$ [D]: Closed-form solution
Computational cost	Expensive	Cheap	Cheap
Feature (1)	2 and 3-dimensional	2-dimensional	2 and 3-dimensional
Feature (2)	Can deal with interaction between local and global failures	Can not deal with interaction between local and global failures	Can deal with interaction between local and global failures

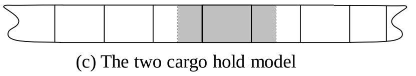
Methods for Progressive Hull Collapse Analysis
- Extent of Analysis



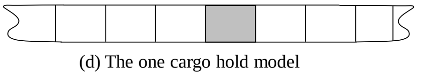
(a) The entire hull model



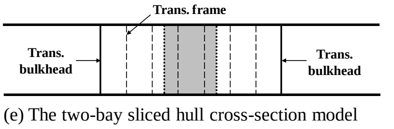
(b) The three cargo hold model



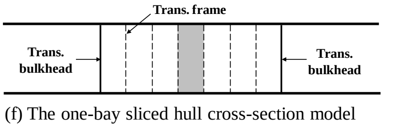
(c) The two cargo hold model



(d) The one cargo hold model



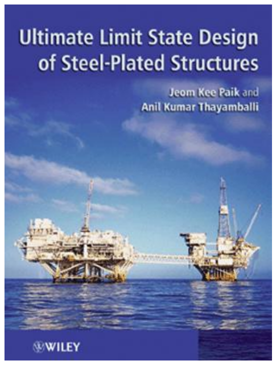
(e) The two-bay sliced hull cross-section model



(f) The one-bay sliced hull cross-section model

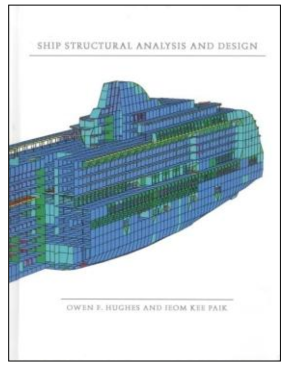
Theory of the ALPS/ULSAP Method

ALPS/ULSAP (Analysis of Large Plated Structures / Ultimate Limit State Assessment Program), developed by Prof. J.K.Paik, Pusan National University



Ultimate Limit State Design of Steel-Plated Structures (2003)

Paik & Thayamballi



Ship Structural Analysis and Design (2010)

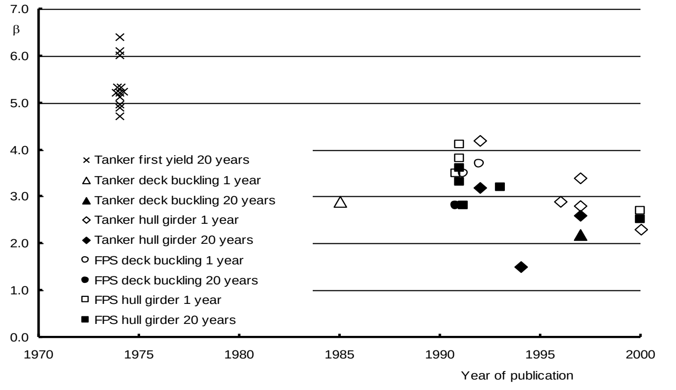
Hughes & Paik

4. Ship and Offshore Structural Design: Recent Advances and Future Trends

4.2 Reliability Based Methods

Reliability Based Design Criteria

$$\text{Reliability} = \beta = 1\text{-}P_f \geq \beta_o$$

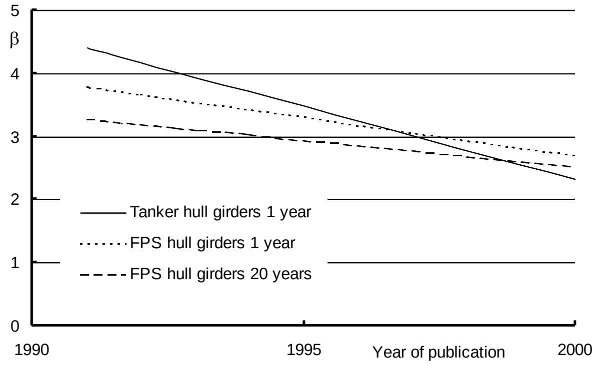


Variation of calculated reliability indices for tankers and FPSs

[Ref.] J.K. Paik and P.A. Frieze, Ship Structural Safety and Reliability, Progress of Structural Engineering and Materials, Vol.3, 2001, pp.198-210.

Reliability Based Design Criteria

$$\text{Reliability} = \beta = 1\text{-}P_f \geq \beta_o$$



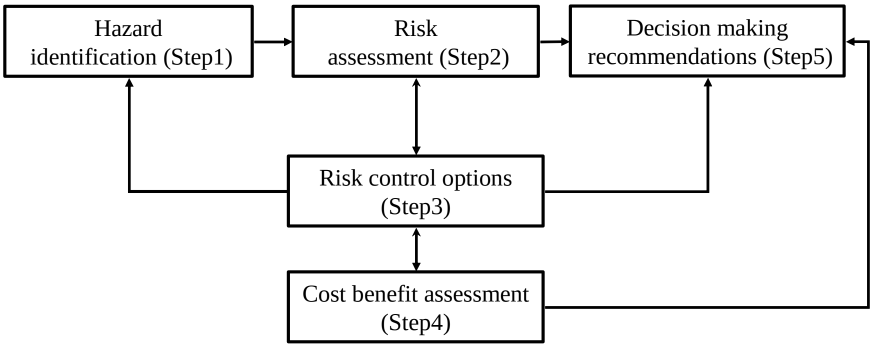
Trend f calculated reliability indices for tankers and FPSs

[Ref.] J.K. Paik and P.A. Frieze, Ship Structural Safety and Reliability, Progress of Structural Engineering and Materials, Vol.3, 2001, pp.198-210.

4. Ship and Offshore Structural Design: Recent Advances and Future Trends

4.3 Risk Based Methods

Risk Based Design Method (Formal Safety Assessment)

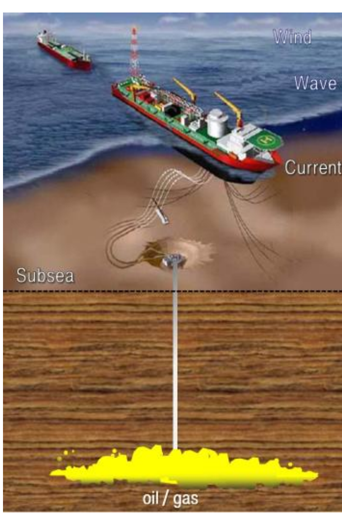


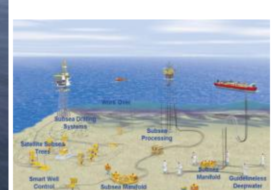
What is Risk? How to Manage Risk?

$$R = \sum_i F_i \times C_i$$

- Asset risk
  - Damage to structures and equipment
  - Duration of production delay (downtime)
- Environmental risk
  - Amount of oil that spills out of the offshore installation
- Personnel risk
  - Loss of life

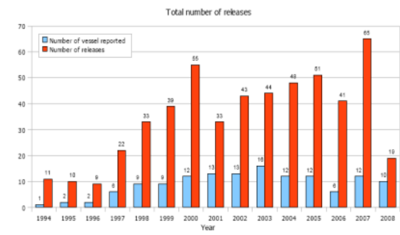
FPSO for Oil and Natural Gas Production



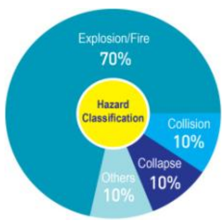


Vessel (hull), topsides (process facility), mooring, umbilicals/risers/flowlines, subsea, and export system

Oil/Gas Leak Resulting in Explosion and Fire



Source: HSE



Pipe Alpha Accident

- 6th July 1988, UK
- 167 people killed
- Property damage of 1.4billion US$
- Risk based engineering became mandatory since the Pipe Alpha accident

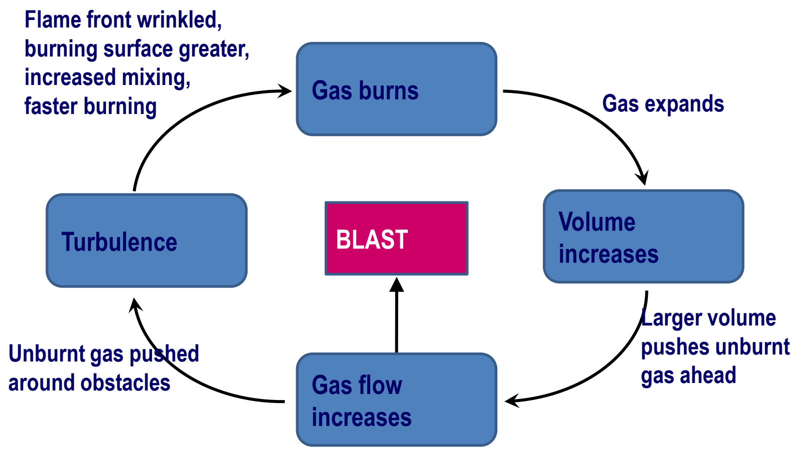
Deepwater Horizon Accident

- 20th April 2010, Gulf of Mexico
- 11 people killed, 17 people wounded
- Environmental damage of approx. 30 billion US$

Hydrocarbon Explosions and Fires

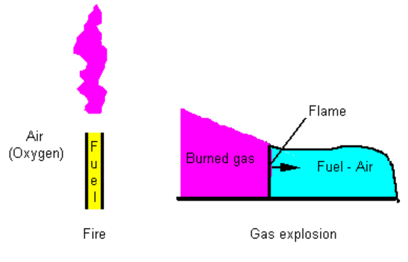
- Hydrocarbons can explode through ignition when combined with an oxidiser (usually air). Thus, when the temperature rises to the point at which hydrocarbon molecules react spontaneously to an oxidiser, combustion takes place. This hydrocarbon explosion causes a blast and a rapid increase in overpressure.
- Fire is a combustible vapour or gas that combines with an oxidiser In a combustion process that is manifested by the evolution of light, heat, and flame.
- The impact of overpressure from explosions and that of elevated temperature from fire are the primary concern in terms of the actions That result from hazards within the risk assessment and management framework.

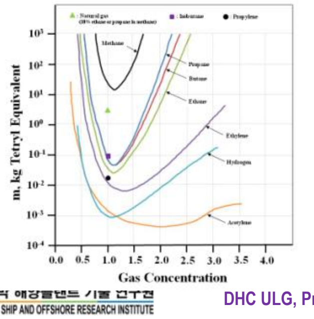
Mechanism of Gas Explosion – Depending on Topology and Geometry



CONGESTION? CONFINEMENT?

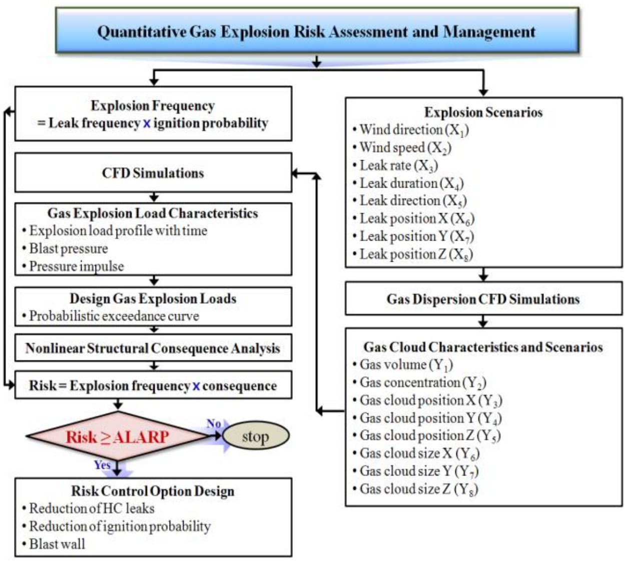
Factors Affecting Explosions and Fires





- Wind direction
- Wind speed
- Leak rate
- Leak direction
- Leak duration
- Leak position (x)
- Leak position (y)
- Leak position (z)
- Type of oil or gas (molecules)
- Concentration ratio
- Temperature of oil or gas (LNG Cryogenic -163 degree C)

Quantitative Gas Explosion Risk Assessment and Management (1/2)

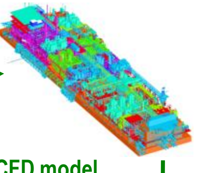


EFEF JIP Procedure for Explosion Risk Assessment and Management (2/2)

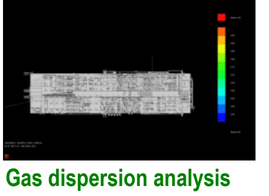
CAD model

Selection of credible scenarios involving PDF parameters of leak and environment conditions

Latin hypercube sampling technique

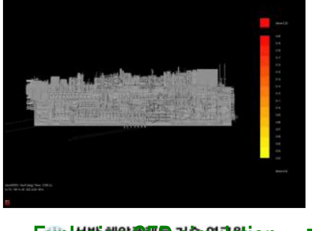


CFD model

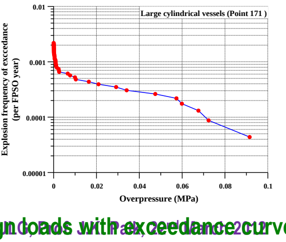


Gas dispersion analysis

Selection of credible scenarios involving PDF parameters of gas cloud condition



Explosion CFD simulation

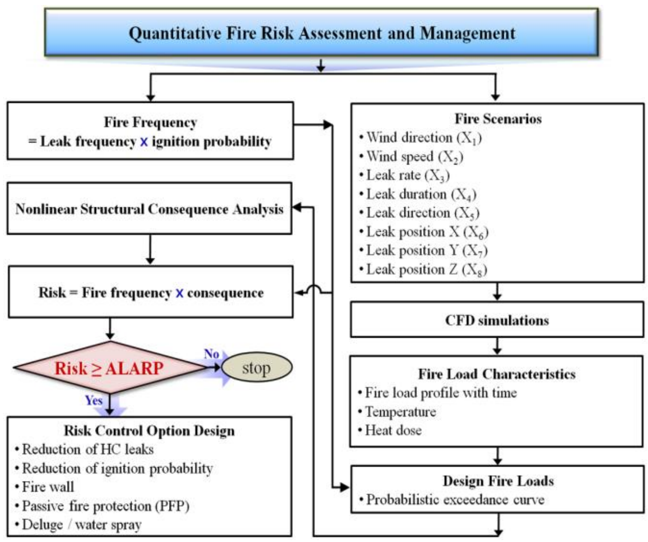


Design loads with exceedance curve

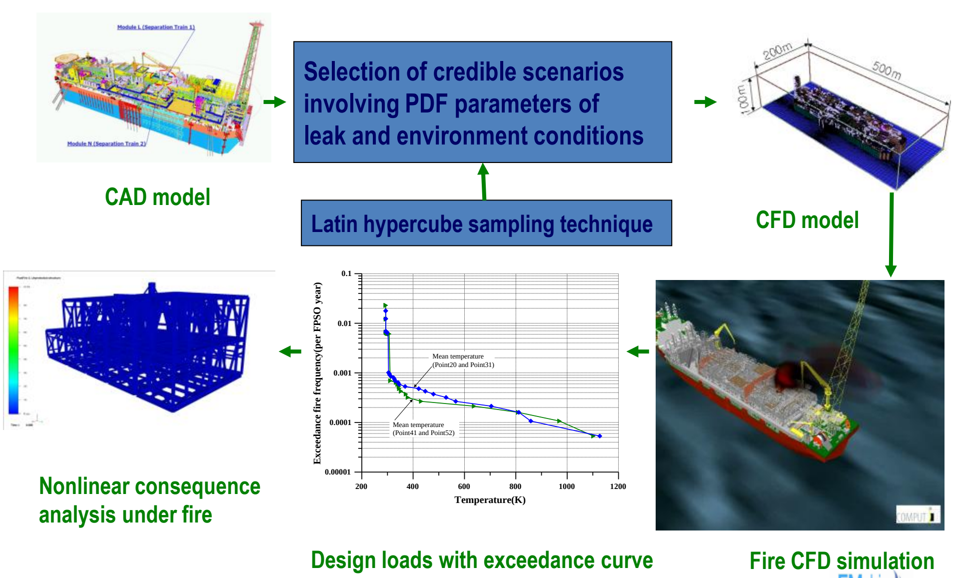
Nonlinear consequence analysis under explosion

선박 해양플랜트 기술 연구원 THE SHIP AND OFFSHORE RESEARCH INSTITUTE
DHC ULG, Prof. J.K. Paik, 22nd March 2012
www.EMSHIP.eu

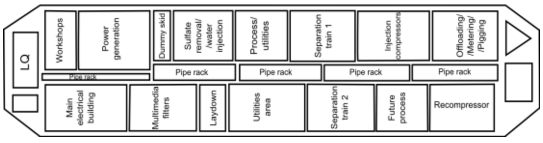
EFEF JIP Fire Risk Assessment and Management (1/2)

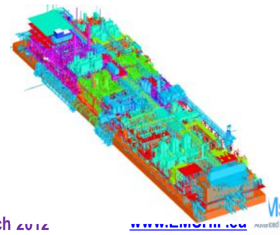


EFEF JIP Procedure for Fire Risk Assessment and Management (2/2)

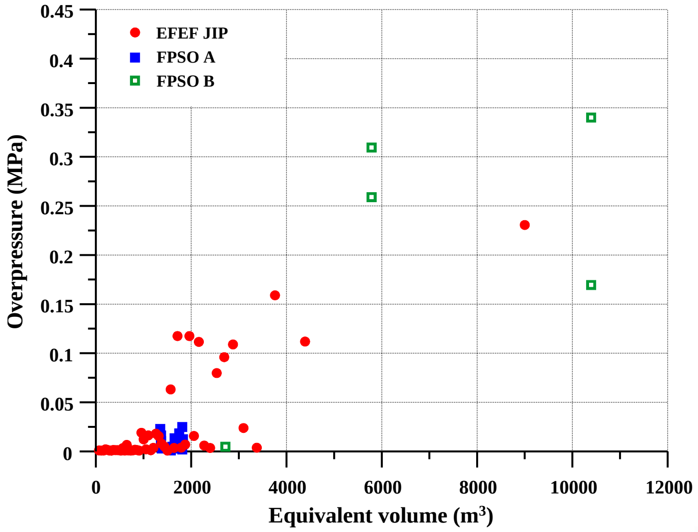


Applied Example: VLCC Class FPSO Topsides

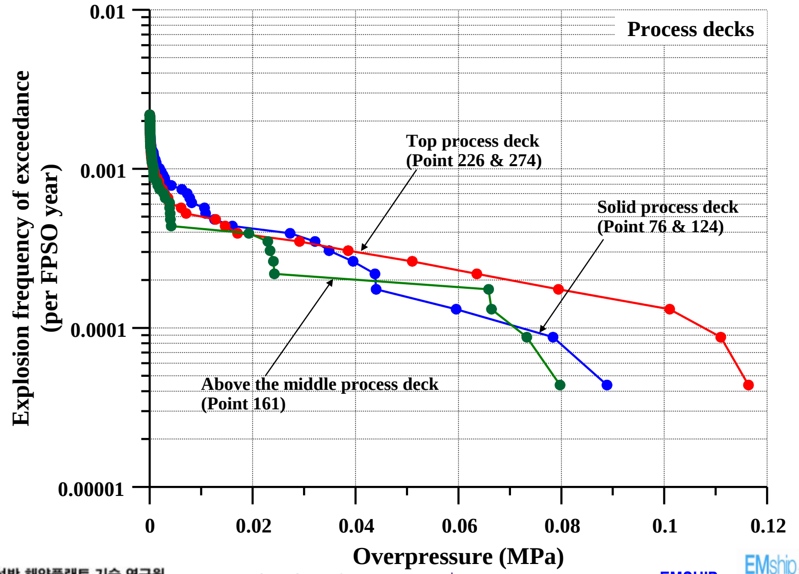




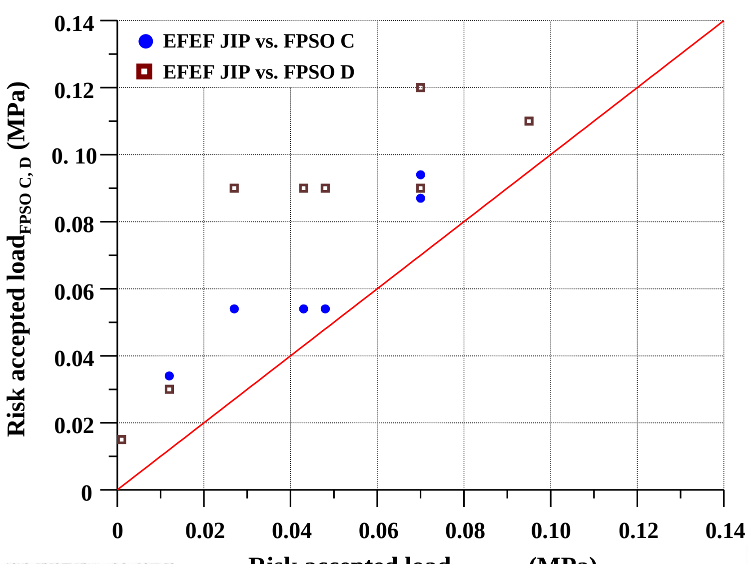
Effect of Gas Cloud Volume on Maximum Overpressure – Comparison between EFEF and Existing FPSO Practices



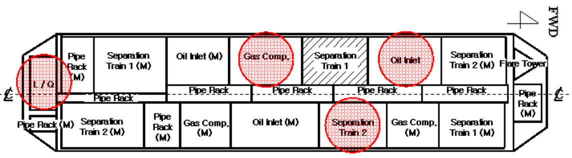
Design Explosion Loads with Exceedance Curves

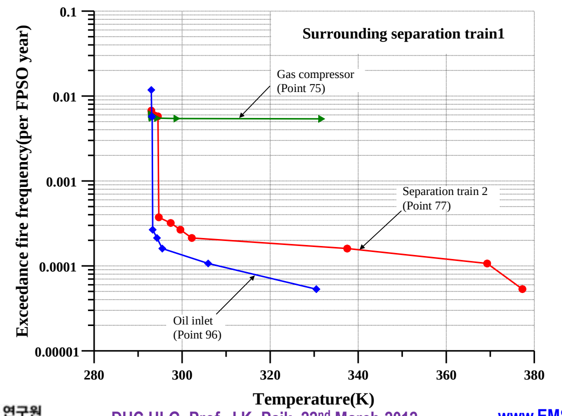


Design Explosion Loads – Comparison between EFEF JIP and Existing FPSO Practic

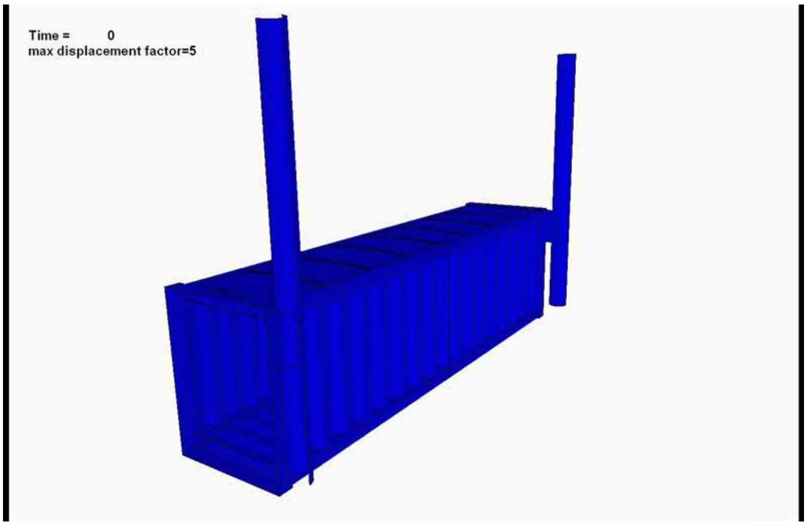


Design Fire Loads with Exceedance Curves

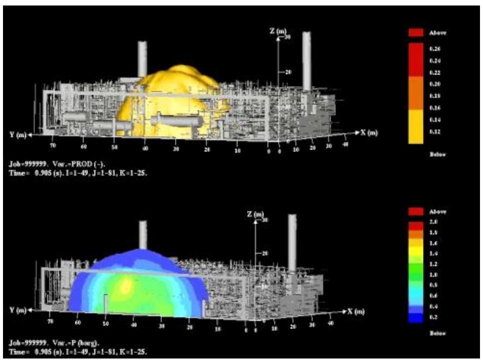


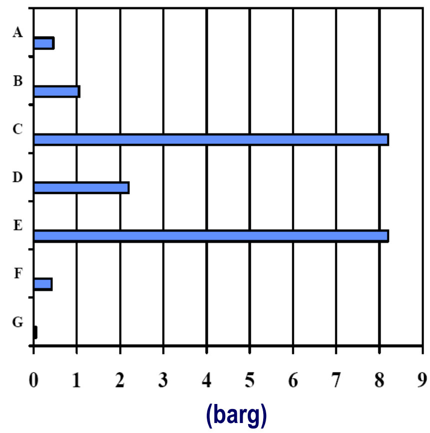


Nonlinear Structural Consequence Analysis – Escape Route

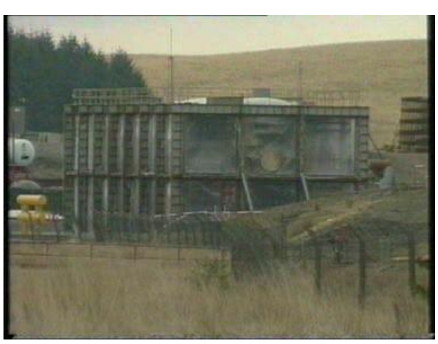


CFD Explosion Simulations





Gas Explosion Tests with or without Water Sprays (1/2)
- Importance of Risk Management



Without water sprays

With water sprays

Source: © The Steel Construction Institute, Fire and Blast Information Group

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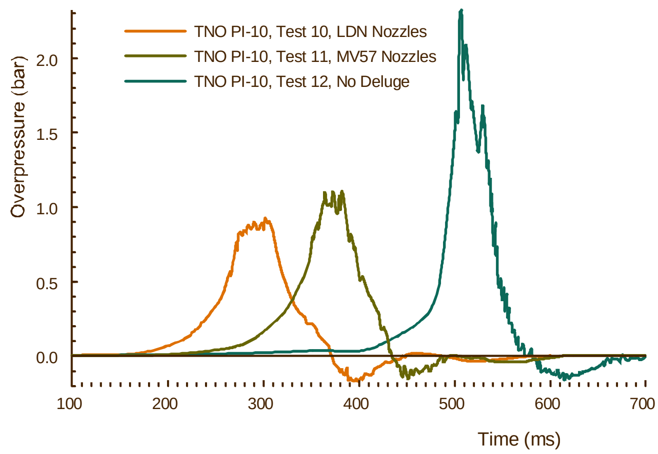
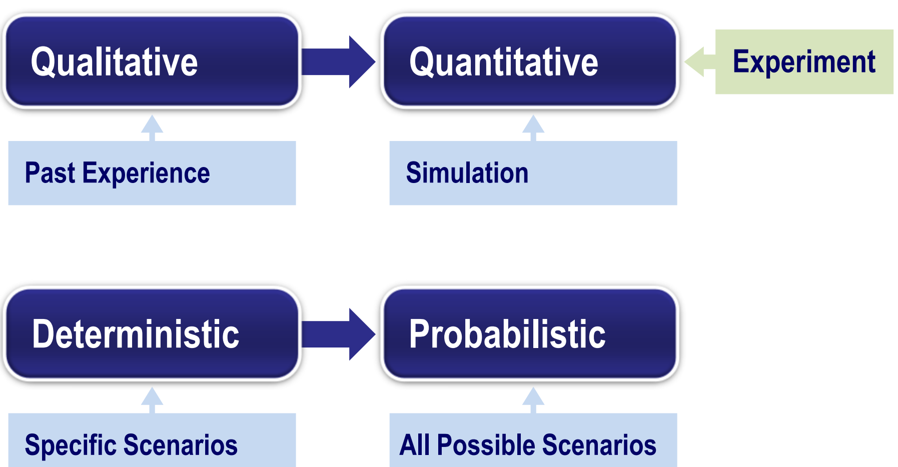
DHC ULG, Prof. J.K. Paik, 22nd March 2012
www.EMSHIP.eu

Gas Explosion Tests with or without Water Sprays (2/2)
- Importance of Risk Management



Source: © The Steel Construction Institute, Fire and Blast Information Group

Trends in Risk Assessment



Human Factors Engineering

- Over the last decade, the likelihood and consequences of marine casualties have certainly declined, in part due to technological improvements.
- However, accidents continue to occur while ships and offshore installations are in service, regardless of the significant efforts exerted toward eliminating them.
- Furthermore, the public's growing concerns and intolerance for safety, health and environmental risk suggest that more has to be done going forward.
- The best way of achieving this goal is to reduce human error by better understanding ocean environmental phenomena and then apply human factor and ergonomic best practices to vessel design, engineering, construction, and operation.

In Association with the Insignia of Doctor Honoris Causa of The University of Liège
Thursday 22nd March 2012

Thanks to

- Ecole Centrale de Nantes (ECN) to welcome this conference
- EMSHIP (European ERASMUS MUNDUS), coordinated by the University of Liège and ECN