Recent Advances and Future Trends on Ship and Offshore Structural Design

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4. Ship and Offshore Structural Design: Recent Advances and Future Trends
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   4.2 Reliability Based Methods
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- 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

Main Campus of Pusan National University
- Total number of students = 31,000
- Total number of NAOE students = 380 (undergraduate)/120 (graduate)
2. The Ship and Offshore Research Institute at Pusan National University

Organization of The KOSORI
Research Staff (as of March 2012)

<table>
<thead>
<tr>
<th>Research Staff</th>
<th>Number</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty Member</td>
<td>4</td>
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<tr>
<td>Chair Professor</td>
<td>1</td>
<td>Former Deputy Minister of Science and Technology, Korea</td>
</tr>
<tr>
<td>Visiting Professor</td>
<td>1</td>
<td>von Karman Chair Professor, University of California at Irvine, USA</td>
</tr>
<tr>
<td>Research Professor</td>
<td>2</td>
<td></td>
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<tr>
<td>Research Engineer</td>
<td>6</td>
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<tr>
<td>Graduate Student</td>
<td>19</td>
<td>Master</td>
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<tr>
<td>PhD</td>
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<tr>
<td>Technician</td>
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<td></td>
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<tr>
<td>Administrative</td>
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<tr>
<td>Total</td>
<td>52</td>
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</tbody>
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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.G. Song, Senior Executive Vice President, Hanjin Heavy Industries
- Mr. T.H. Park, Senior Executive Vice President, STX Offshore and Shipbuilding
- Mr. J.B. Bui, Executive Vice President, DSME
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- Emeritus Prof. O.F. Hughes, Virginia Tech., USA
- Emeritus Prof. R.J. McKee, University of Newcastle, Australia
- Prof. R. Sav, Oxford University, UK
- Prof. Y. Zai, Chajang University, China

Research Facilities – Computer Program

<table>
<thead>
<tr>
<th>No.</th>
<th>Program</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ANSYS</td>
<td>Linear / nonlinear finite element analysis</td>
</tr>
<tr>
<td>2</td>
<td>ANSYS CFX</td>
<td>CFD simulations</td>
</tr>
<tr>
<td>3</td>
<td>LS-DYNA</td>
<td>Linear / nonlinear dynamic / impact nonlinear finite element analysis</td>
</tr>
<tr>
<td>4</td>
<td>ALPS</td>
<td>Ultimate strength analysis of plates, stiffened panels and hull girders</td>
</tr>
<tr>
<td>5</td>
<td>FLACS</td>
<td>CFD simulations for Dispersion and explosions</td>
</tr>
<tr>
<td>6</td>
<td>KFX</td>
<td>CFD simulations for fires</td>
</tr>
<tr>
<td>7</td>
<td>DNV Neptune</td>
<td>Risk calculations</td>
</tr>
<tr>
<td>8</td>
<td>CAD system</td>
<td>Drawing</td>
</tr>
</tbody>
</table>
Research Facilities – Test Facilities (1/7)

- 1000kN Universal Test Machine
- 1800kN Dynamic Actuator
- 2800kN Static Actuator
- Static/Dynamic Test Frame
- High Speed Test Machine
- 600bar Subsea Chamber (under Construction)

Test specimen
(G.L.=50mm, A=500mm²)

Test 1
Test 2
Test 3

Load (kN)

Time (sec)

0 0.004 0.008 0.012 0.016 0.02

v=14.8m/s (G.L.=50mm, Strain rate=300 s⁻¹), Mass=250kg

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)

Research Facilities – Test Facilities (4/7)
Research Facilities – Test Facilities (5/7)

UK  Explosion and Fire Test
    Spekeford, UK

Norway Fire Test
    Trondheim, Norway

USA  Explosion and Fire Test
     Houston, USA

Korea Explosion and Fire Test
     Hadong, Korea

Research Facilities – Test Facilities (6/7)
3. General Trends in Maritime Industry
3. General Trends in Maritime Industry

3.1 Green Shipping
Global Warming and Climate Change

- Global warming refers to the rising average temperature of Earth's atmosphere and oceans and its related effects.
- Warming of the climate system is unequivocal, and scientists are more than 90% certain most of it is caused by increasing concentrations of greenhouse gases produced by human activities such as deforestation and burning fossil fuel.
- These findings are recognized by the national science academies of all the major industrialized countries.
- 70% of greenhouse gas is CO₂ from fossil fuel.

![Global Surface Temperature Change](Source: Wikipedia)

![Greenhouse gas emission](Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007))

**Source Breakdown of CO₂ Emissions**

- Shipping (3.3% = International Shipping 2.7% + Domestic Shipping & Fishing 0.6%)
- International Aviation (1.9%)
- Others (15.2%)
- Electricity and Heat Production (35.0%)
- Land Transport (21.8% = Road 21.3% + Rail 0.5%)
- Industries (22.9% = Manufacturing Industries and Construction 18.2% + Other Energy Industries 4.6%)
### Pollution from Ships to the Environment

#### Air pollution
- Sulphur oxides (SOx)
- Nitrogen oxides (NOx)
- Particulate matter (PM)
- Volatile organic compounds (VOCs)

#### Water pollution
- Wastewater
- Bilge water
- Cooling water
- Grey water
- Anti-fouling remains
- Non-biodegradable waste

#### Ground pollution
- Noise
- Vibration
- Radiation

#### Pollution on shore
- Particulate matter
- Chemical residues
- Noise

### Active Methods for Reduction of CO₂ Emissions from Ships

<table>
<thead>
<tr>
<th>Measure</th>
<th>Method</th>
<th>How To</th>
<th>Reduction(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Fuel source</td>
<td>• Natural gas</td>
<td>20-30%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Nuclear</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Others, e.g., solar, wind, hydrogen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Structural material</td>
<td>• New high tensile steel material</td>
<td>2-5%</td>
</tr>
<tr>
<td></td>
<td>Structural design</td>
<td>• Structural optimization</td>
<td>2-5%</td>
</tr>
<tr>
<td></td>
<td>Hull form design</td>
<td>• Hull form optimization</td>
<td>2-3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bulbous bow optimization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Propeller design</td>
<td>• High efficiency propeller</td>
<td>2-3%</td>
</tr>
<tr>
<td></td>
<td>Device</td>
<td>• Shaft generator</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pre-swirl stator (PSS)</td>
<td>3-6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Water heat recovery system (WHRS)</td>
<td>3-4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Air cavity system, micro bubble</td>
<td>7-10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• SOx/NOx reduction device</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operation</td>
<td>• Trim operation</td>
<td>3-4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Optimum weather routing</td>
<td>4-5%</td>
</tr>
</tbody>
</table>
Active Methods for Reduction of CO₂ Emissions from Ships

- NOx/SOx emission control (Protect the environment)
- Anti-pirate System (To avoid and delay pirate attacks)
- Water Pollution Prevention (Protect the environment)
- VOC Reduction system (Protect the environment)

Pre-swirl Stator (Power saving 5%)
ME-GI Engine
Waste Heat Recovery System (Fuel oil saving 2.8%)
Air-Bubble

Passive Methods for Reduction of CO₂ Emissions

<table>
<thead>
<tr>
<th>Measure</th>
<th>Method</th>
<th>How To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>Carbon treatment</td>
<td>• Carbon capture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Carbon transportation via ship or pipeline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Carbon storage</td>
</tr>
</tbody>
</table>

VOC = volatile organic compound
3. General Trends in Maritime Industry
3.2 Development of Deepwaters
Demand of Oil in China and United States

![Chart showing the demand of oil in China and United States from 2007 to 2030. The chart includes lines for US-EIA, US-DWL, China-EIA, China-DWL, and China (Korea model). The chart indicates a significant increase in demand for both countries, with China expected to surpass the US by 2030.]

Global Oil Supplies

![Diagram showing global oil supplies from 2000 to 2030. The diagram includes information on new reservoirs, fields under development (FUD), fields under appraisal (FUA), fields in production (FIP), and natural gas. The diagram also highlights the peak oil period and shows the percentage decrease in oil supplies.]

Source: IHS Cambridge Energy Research Associates, 90203-3
Development of Energy Sources in Deepwaters

- Oil, natural gas, gas hydrate, minerals (rare materials)
- Renewable energy sources (wind, current)
- World market size of more than 500 billion 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
3.3 Human Factors Engineering

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.
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
- Experimental Investigation
Cause 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.

International Rules and Standards

HSE & E – Health, Safety, Environment & Ergonomics

IACS CSR/H-CSR
IMO GBS
ISO ISO 18072

Advanced Technologies

First-Principles-Based Direct Methods
Limit States-Based Methods
Risk-Based Methods
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 = \( \beta = 1 - P_f \geq \beta_o \)

Risk \( \leq \) ALARP

where,
- \( C_d \) = Design capacity
- \( D_d \) = Design demand
- \( P_f \) = Probability of failure
- \( \beta \) = Reliability index
- \( \beta_o \) = 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

Limit States Based Structural Design Optimization

Modeling of Structure & Loads

Structural Response Analysis
Calculate Load Effects, $Q$

Limit State Analysis
Calculate Limit Values of Load Effects, $Q_L$

Evaluation
(A) Formulate constraints
$\gamma_1 \gamma_2, \gamma_3 \geqslant Q \leqslant Q_L$
(B) Evaluate adequacy
Constraints satisfied? Objective achieved?

Optimization

Objective

Weight or building cost
**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

**Methods for Progressive Hull Collapse Analysis**

<table>
<thead>
<tr>
<th>Method</th>
<th>NLFEM</th>
<th>ISUM/Smith Method</th>
<th>ISFEM (ALPS/HULL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric modeling</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Formulation technique</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numerical formulation</td>
<td></td>
<td>Closed form formulation</td>
<td>Numerical formulation</td>
</tr>
<tr>
<td>[ \sigma = \int [B^T[D]B]d\sigma ]</td>
<td></td>
<td>[ \sigma = \Phi \sigma ]</td>
<td>[ \sigma = \int [B^T[D]B]d\sigma ]</td>
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<tr>
<td>[D]: Numerical formulation</td>
<td></td>
<td>[ \Phi = \text{edge function} ]</td>
<td>[D]: Closed-form solution</td>
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<tr>
<td>( -1 ) for ( x &lt; -1 )</td>
<td></td>
<td>( \Phi = \text{edge function} )</td>
<td>( \Phi = \text{edge function} )</td>
</tr>
<tr>
<td>( +1 ) for ( 1 &lt; x &lt; 1 )</td>
<td></td>
<td>( \Phi = \text{edge function} )</td>
<td>( \Phi = \text{edge function} )</td>
</tr>
<tr>
<td>( \sigma_u^I )</td>
<td></td>
<td>( \sigma_u^I )</td>
<td>( \sigma_u^I )</td>
</tr>
<tr>
<td>Computational cost</td>
<td>Expensive</td>
<td>Cheap</td>
<td>Cheap</td>
</tr>
<tr>
<td>Feature (1)</td>
<td>2 and 3-dimensional</td>
<td>2-dimensional</td>
<td>2 and 3-dimensional</td>
</tr>
<tr>
<td>Feature (2)</td>
<td>Can deal with interaction between local and global failures</td>
<td>Can not deal with interaction between local and global failures</td>
<td>Can deal with interaction between local and global failures</td>
</tr>
</tbody>
</table>
Methods for Progressive Hull Collapse Analysis - Extent of Analysis

(a) The entire hull model

(b) The three cargo hold model

(c) The two-bay sliced hull cross-section 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

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

\[ \text{Reliability} = \beta = 1 - P_f \geq \beta_0 \]

Variation of calculated reliability indices for tankers and FPSs

Reliability Based Design Criteria

Reliability = $\beta = 1 - P_f \geq \beta_0$

Trend of calculated reliability indices for tankers and FPSs


4. Ship and Offshore Structural Design: Recent Advances and Future Trends
4.3 Risk Based Methods
Risk Based Design Method

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
Oil/Gas Leak Resulting in Explosion and Fire

Source: HSE
Pipe Alpha Accident

- 6th July 1988, UK
- 167 people killed
- Property damage of 1.4 billion 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 Geometrical Constraints

1. Flame front wrinkled, burning surface greater, increased mixing, faster burning
2. Turbulence
3. Gas burns
4. Gas expands
5. Volume increases
6. Larger volume pushes unburnt gas ahead
7. Gas flow increases
8. Unburnt gas pushed around obstacles
9. BLAST
10. CONGESTION?
11. CONFINEMENT?

www.EMSHIP.eu
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)

Selection of credible scenarios involving PDF parameters of leak and environment conditions
Selection of credible scenarios involving PDF parameters of gas cloud condition

EF EF JIP Procedure for Explosion Risk Assessment and Management

CAD model
Latin hypercube sampling technique
CFD model
Gas dispersion analysis
Explosion CFD simulation
Design loads with exceedance curve
Nonlinear consequence analysis under explosion
Selection of credible scenarios involving PDF parameters of leak and environment conditions

Latin hypercube sampling technique

Nonlinear consequence analysis under fire

Design loads with exceedance curve

Fire CFD simulation

Applied Example: VLCC Class FPSO Topsides
Effect of Gas Cloud Volume on Maximum Overpressure – Comparison between EFEJIP and Existing FPSO Practices

![Graph showing overpressure versus equivalent volume for different FPSOs and the EFEJIP project.]

Design Explosion Loads with Exceedance Curves

![Graph showing the exceedance curves for different process decks, including top, solid, and middle decks.]

DHC ULG, Prof. J.K. Paik, 22nd March 2012
www.EMSHIP.eu
Design Explosion Loads – Comparison between EEFJ JIP and Existing FPSO Practice

![Graph showing comparison between EEFJ JIP and Existing FPSO Practice](image)

Design Fire Loads with Exceedance Curves

![Diagram showing design fire loads with exceedance curves](image)
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

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

Qualitative → Quantitative
- Past Experience → Simulation
- Specific Scenarios → All Possible Scenarios

Deterministic → Probabilistic

In Commemoration of Doctor Honoris Causa of The University of Liège
Thursday 22nd March 2012

Recent Advances and Future Trends on Ship and Offshore Structural Design

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