A global R&D hub for advanced safety studies

Prof Jeom Kee Paik introduces the research activities and test facilities of the International Centre for Advanced Safety Studies at KOSORI, which focus on improving the safety of structures in VUCA environments

Ships and offshore structures are often subjected to extreme conditions and accidents while in service. Despite significant efforts at prevention, collisions, grounding, fires, and explosions inevitably occur, leading to catastrophes that can affect personnel, assets and the environment. Such catastrophes are the result of volatility, uncertainty, complexity and ambiguity (VUCA). Actions and the action effects of structures under extreme conditions and accidents are inevitably highly nonlinear and non-Gaussian, involving multiple physical processes, multiple scales and multiple criteria.

It is not possible to represent VUCA environments with only a few scenarios; rather, a full set of event scenarios are carefully selected on the basis of probabilistic characterisation of random variables affecting accidental events. It is now generally recognised that technologies for quantitative risk assessment and management are the best way to effectively manage VUCA environments, and eventually resolve their challenges. Multidisciplinary approaches that take advantage of both advanced computational modelling and large-scale physical model testing are required.

The objective of the International Centre for Advanced Safety Studies (ICASS) at the Korea Ship and Offshore Research Institute (KOSORI), therefore, is to play a leading global role in enhancing the safety of structures and infrastructures against extreme conditions and accidents, and thus mitigate the catastrophic consequences of accidents.

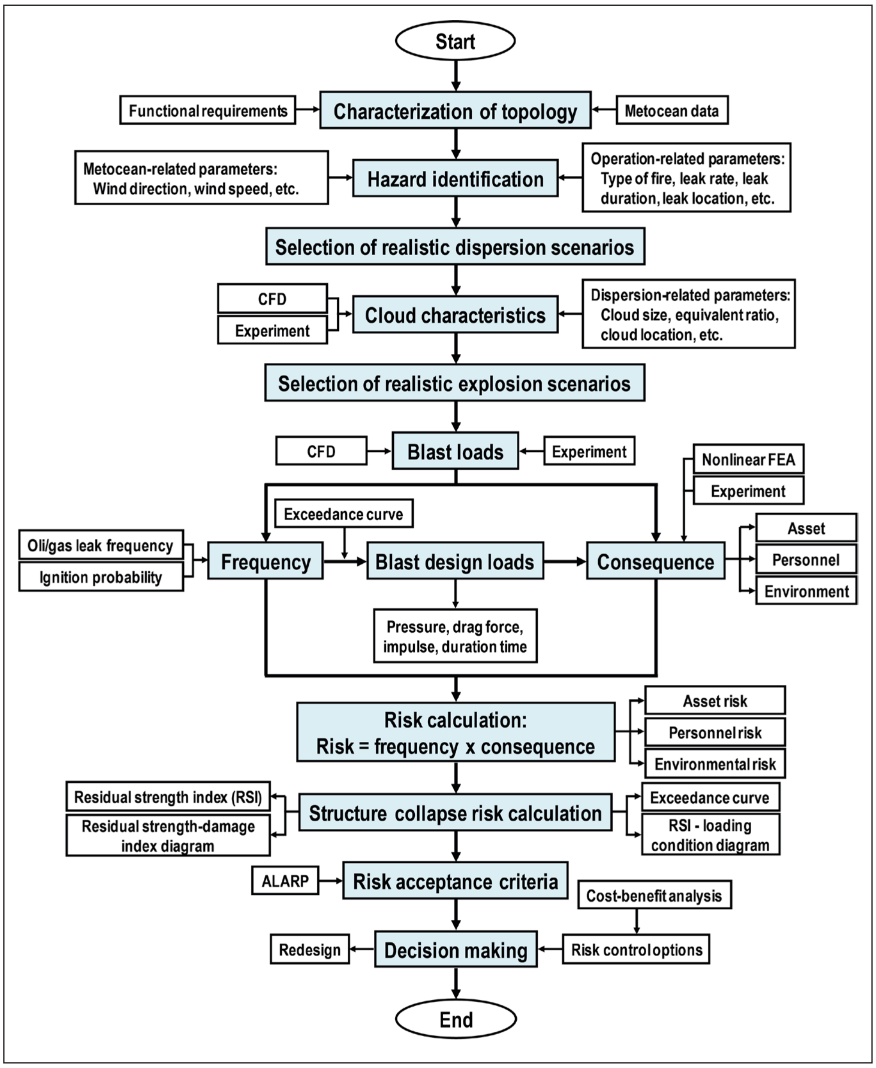


Figure 1. ICASS procedure for quantitative risk assessment and management of structures and infrastructures at explosions

Frequency and consequence

In the engineering community, risk is defined as a product of frequency and consequence. This is shown in Figure 1, an example of an ICASS procedure for quantitative risk assessment and management, in this case for explosions.

While frequency can be calculated using a large database of historical statistics regarding accidents (such as the European Marine Casualty Information Platform [EMCIP]), consequences are determined by advanced computational models and large-scale physical model tests.

Computational fluid dynamics methods are useful for determining action characteristics, and nonlinear finite element methods are now commonly used to compute structural crashworthiness associated with geometric and material nonlinearities involving buckling, plasticity, crushing and fracture. A variety of advanced computational models have been developed in association with ICASS research programmes funded by the Lloyd's Register

Figure 2. Dropped object test facility

Foundation. These include models for the selection of realistic scenarios, frequency calculation, determination of action characteristics, simulation of action effects and structural crashworthiness, calculation of risks (personnel, assets and the environment), establishment of exceedance curves, definition of risk acceptance criteria, and planning of risk management options.

However, computational models are not sufficient to ensure accurate results; large-scale physical model testing is essential to validate them and to identify the complex response characteristics and action effects of structures under extreme and accidental conditions.

In 1638, Galileo said these words about scaling laws: "If the size of a body be diminished, the strength of that body is not diminished in the same proportion; indeed the smaller the body the greater its relative strength. Thus, a small dog could probably carry on his back two or three dogs of his own size, but I believe that a horse could not carry even one of his own size."

In reality, as no adequate scaling laws are available to convert from small scale model test results to full-scale structure responses under extreme conditions and accidents, testing should be undertaken on full- or large-scale structure models, which can then be combined with advanced computational models.

Test facilities

For this purpose, ICASS has built large-scale physical model test facilities on 23.1 ha of land in Hadong, South Korea, with the financial support of central and local governments. Using these facilities, ICASS is dedicated to the development of a test database of large-scale structural models subjected to extreme and accidental conditions. External institutes and organisations are also welcome to make use of the facilities.

Figures 2 and 3 present selected test KOSORI facilities, which allow experimentation on full/large-scale physical models. A complete list of test facilities follows below, and each facility's full performance and functional capabilities can be accessed at ~~www.korosri.org~~ or www.icass.center.

High Speed Impact Test Facility. Large ships and offshore structures are composed of steel plate panels with a thickness of over 20 mm. The mechanical properties of steel are characterised by a tensile coupon test. An impact test is used to characterise strain rate effects at high-speed loading conditions due to collisions or explosions. Traditionally, tensile coupon testing of material has been undertaken with unrealistically thin test specimens (e.g., with 1 mm thick), and it has been presumed that the test results obtained from such specimens are applicable to thick materials. This assumption is serviceable for quasi-static loading conditions, but it is invalid for high speed or impact loading conditions. This test facility can deal with tensile coupon test specimens with a thickness of up to 20 mm at a maximum loading speed of 25 m/s. The effects of low temperatures and cryogenic conditions can also be treated using a temperature chamber.

Full-/Large-Scale Structural Failure Test Facility. Ships and offshore structures under extreme loads show highly nonlinear behaviour until and after the ultimate strength is reached. Not only buckling and plasticity, but also crushing and fracture occur. Small-scale structural models are inadequate for examining the true responses of structural crashworthiness because no relevant scaling laws are available (for many reasons, including fabrications, initial imperfections, and other nonlinear effects). This test facility aims to test full- or large-scale structure models, by allowing application of up to 30 MN in force. The effects of low temperatures can also be treated in association with Arctic operation. Test programmes examining full-scale stiffened plate structure models of a 22,000 TEU containership under uniaxial or biaxial compressive loading and 1/6 scaled hull girder structure models of an 1,900 TEU containership under vertical bending moments or combined vertical bending and torsional moments are now being undertaken using this test facility.

Dropped Object Test Facility. Ships and offshore structures are often subjected to impact loads due to collisions or dropped objects. In Arctic operation or with LNG cargo systems, they may also be subjected to low temperatures or cryogenic conditions. In this situation, the structures show nonlinear behaviour involving brittle fracture, together with high strain rate effects. Structures at elevated temperatures due to fires may also be subjected to impact loading, again showing highly nonlinear structural responses. Full- or large-scale models can be used to capture the true responses of structures under impact loading.

Hyperbaric Pressure Test Facility. Subsea equipment and tubular members (e.g., risers or pipelines) used for developing offshore oil and gas in deep water or for deep sea mining are subjected to ultra-high pressure loads. The size of this hyperbaric test chamber is 1.8 m in diameter and 4 m deep, and thus full-scale or very large-scale models can be tested directly. The maximum pressure applied is 825 bar, which is equivalent to 8,250 m water depth.

Vertical and Horizontal Furnace Test Facility. In this fire test facility, the increase of temperatures and fire energy (heat flux) can be controlled. Fire dynamics differ from structural positioning, as they are associated with conduction, convection and radiation. Two types of furnace are available, vertical and horizontal. The fire resistance of walls, doors and windows can be tested on full-scale models.

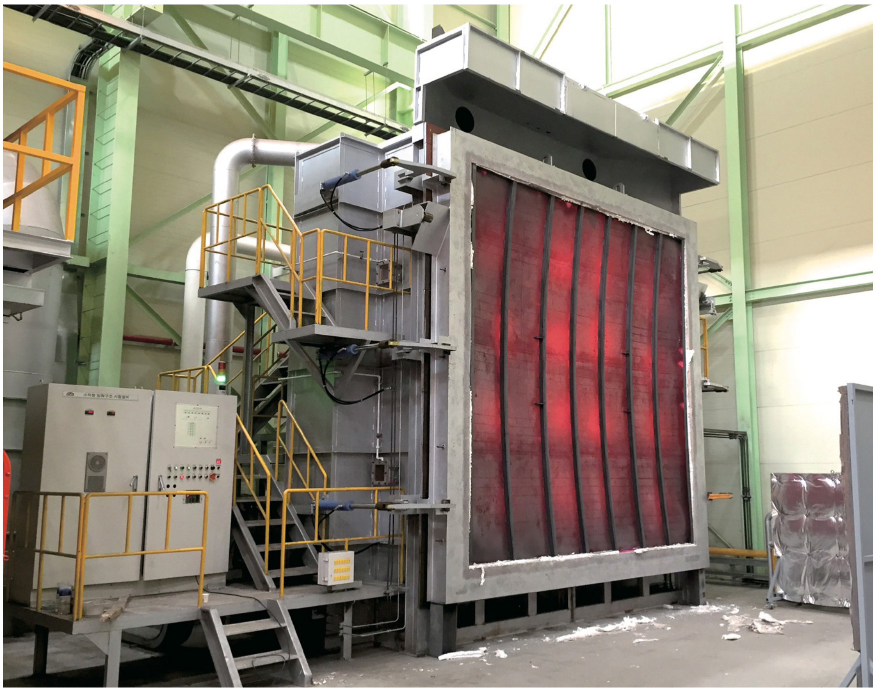
Fire Collapse Test Facility. In fires, structures are vulnerable to system collapse, because elevated temperatures significantly reduce the mechanical properties of material, while external forces still continue to apply. This test facility can deal with large-scale structure models at elevated temperatures due to fires and under external compressive forces that cause buckling collapse.

Indoor Jet/Pool Fire Test Facility. Jet or pool fire is the most frequent type of fire in industrial production. This indoor fire test facility is used to examine the structural failure characteristics associated with jet or pool fires, with or without water spray or deluge systems.

Outdoor Fire/Explosion Test Facility. Fire dynamics are significantly affected by environmental conditions such as wind, and by ventilation. It is very difficult to perform fire tests on large structure models inside a building. This test facility is used to examine the time- and space-variant characteristics of fire or explosion actions (loads); elevated temperatures in fires and overpressure loads in explosions can be physically measured. Full- or large-scale physical model testing to examine nonlinear structural consequences in fires or explosions is also performed.

Blast Wall Test Facility. Blast walls are commonly used to protect living quarters in ships and offshore structures against explosions. Given the nature of these structures, blast walls should be as light as possible. This test facility is used to examine the blast responses of walls, doors and windows in explosions.

Figure 3. Vertical-type furnace test facility



Total Integrated Subsea Test Bed. Offshore installations for producing oil and gas in deep waters or for deep sea mining need to facilitate long pipelines and tie-backs on the ocean floor. It is necessary to assess risk and ensure fluid flow in association with multiphase flows, together with the effects of pressures and temperatures. Doing so is extremely important for the successful performance of gas/liquid separation and prevention of hydrate plug formation. This facility is used to test the total integrated performance of subsea systems, including fluid flows in pipelines and gas/liquid separation.

KOSORI combination

Considering that structures and infrastructures under extreme conditions and accidents inevitably involve highly nonlinear responses associated with multiple physical processes, multiple scales and multiple criteria, they cannot be fully identified by mathematical algorithms and related computations alone – physical model testing should be undertaken on full- or large-scale structure models, combined with advanced computational models. It is hoped that technologies using this combination at KOSORI will accurately define and mitigate risks facing ships and offshore structures under extreme conditions and accidents, and ultimately contribute to preventing catastrophes under VUCA environments.

About the author

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