Strength and Reliability Analyses of Energy and Marine Transportation Structures

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Main Works: Materials Science, Fracture Mechanics, Welding Metallurgy, Structural Reliability

Abstract

The recent rapid economic growth in the BRICs has been demanding more energy supply, worldwide. It is expected that total primary energy demand in 2035 will become 1.5 times that of 2009 [1]. Also, mass transportation between countries has become more important for maintaining world's economic activities. In this respect, higher production of oil and gas and safer and more secure mass transportation are one of the major issues in the field of engineering.

A variety of structures, like energy transport pipelines, ships and offshore structures, have been developed, constructed and operated. Safe and secure operations of these structures are definitely important both for human lives and environmental protection. The author's laboratory has been studying strength and reliability of such structures. In the present abstract, part of our studies is briefly introduced. Also, currently undergoing collaboration with Brazilian university is introduced.

Strength and Reliability of Pipelines for Energy Transportation: It is expected that total primary energy supply by natural gas in the world in 2035 will become 1.6 times that of 2009 [1]. Most of natural gas is transported by pipelines. Operation pressure and distance of the pipelines have been increased to satisfy the increasing demand for natural gas supply, in these days. In the future "hydrogen society", mass transportation of hydrogen gas from hydrogen production site to consumption site will be necessary. Furthermore, mass CO_2 transport system will become necessary for realizing Carbon Capture and Storage by transporting anthropogenic CO_2 to storage site like underwater aquifers. New Types of pipelines, like hydrogen and CO_2 pipelines, will become more important in the future. Safe operation is definitely important for these pipelines.

The present author's laboratory has been studying the strength and reliability of high-pressure energy transport pipelines, extensively. Prevention of unstable fracture of the pipelines is one of the most important issues. We conducted full-scale burst tests of high-pressure hydrogen gas pipelines for the first time in the world. Figure 1 shows an image of high-speed camera, demonstrating how a crack propagated along the pipe with velocity as high as 300m/s. A series of the tests proved that a crack did not propagate in hydrogen gas pipelines at longer distance than in natural gas pipelines under the same operating pressure. Along with the full-scale tests, we developed a computer model to simulate unstable crack propagation behaviors in the pipelines. The model demonstrated that hydrogen gas pipelines are safer than natural gas pipelines as far as the unstable crack propagation is concerned.

Fig.1 Full-scale test of hydrogen gas pipeline.

Demand for offshore pipelines is increasing due to

increased offshore oil and gas production and increased natural gas transport connecting the continents. Presently, a computer simulation model for analyzing the strength and reliability of offshore pipelines is under development, along with experiments simulating offshore pipelines at our laboratory. These studies are expected to contribute to design and construction of safe offshore pipelines.

Strength and Reliability of Marine Transportation Structures: Total of marine transportation in 2010 amounted to 1.5 times that of 2000. This trend will be accelerated in the near future. To satisfy this demand, mega-container ships carrying over 10,000 containers are in operation, nowadays. Prevention of fatal damage of the hull structures of these ships is crucially important for maintaining secure marine transportation system and marine environmental protection.

The author's laboratory has been studying the strength and structural reliability of ship-hull structures, especially container ships. The double integrity criterion, that is, prevention of both initiation and propagation of brittle fracture is applied to the design of these ship-hull structures. It is indispensable to eliminate local brittle zones in welds for preventing brittle fracture initiation. At the same time, the structure must maintain capability of arresting a brittle crack which is initiated from the welds. To realize this scenario, it is necessary to fully elucidate the behaviors of a fast propagating crack in steel, microscopically as well as macroscopically. Figure 2 shows an example of electron microscopic image of brittle fracture of steel. These images are analyzed crystallographically as well as micromechanically. Macroscopic crack propagation can be simulated by Finite Element Method. Heterogeneities and anisotropy of steel material are important factors controlling the brittle crack propagation and taken into account in the numerical simulation. Part of these research results has been applied to the establishment of a guideline for prevention of brittle fracture in container ships [3].

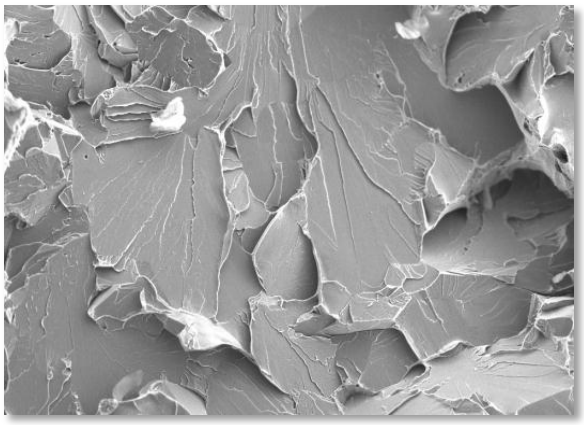

Fig.2 Microscopic analysis of brittle fracture of steel.

Collaborations between the University of Tokyo and Brazilian Universities: Japanese industries have long history of leading the ship-building and structural reliability engineering. The University of Tokyo has been collaborating with the industries through research and education in these fields. Currently, four Brazilian students are staying at the author's department for studying ship-building engineering and material science as pioneers of the *Science without Borders* program. Also, a Japanese shipyard is participating in the educational program for these students. The University of Tokyo is expecting to accept Brazilian students continually by this scheme.

Finally, the University of Tokyo has been holding *Todai Forums* since 2000. These forums are aimed at strengthening academic ties with overseas universities and research institutions through collaborations of education and research in many fields. The *Todai Forum 2013* will be held in Santiago de Chile (Nov. 7-8) and Sao Paulo, Brazil (Nov. 11-12) this year. Many colleagues are welcome to join the forum.

[1] Key World Energy Statistics 2011, IEA.
[2] Statistics by The Japanese Shipowner's Association.
[3]Guidelines on Brittle Crack Arrest Design, Class NK, 2009.