JFE TECHNICAL REPORT
No. 26 (Mar. 2021)

"JWI-CIF^2" JFE Welding Institute — Center for Integrity against Fatigue and Fracture

1. Introduction

In recent years, the demand for improved performance of steel for ships and pipelines has increased. In this field, steel products require weldability and integrity against fracture, as well as weight reduction and higher strength to form large steel structures. Against this background, JFE Steel Corporation has developed new products that have higher integrity, and has also developed various evaluation technologies based on fatigue and fracture mechanics in order to determine the performance of improved steel products and the integrity of steel structures.

On February 19, 2019, JFE Steel established the JFE Welding Institute — Center for Integrity against Fatigue and Fracture (abbreviate as JWI-CIF^2) at its Steel Research Laboratory in Chiba city to conduct innovations through research and development related to fatigue and fracture mechanics.

The JWI-CIF^2 is the largest class facility in Japan and overseas with a number of large-scale testing equipment for fatigue and fracture mechanics area. It conducts evaluation of the fracture performance of actual-scale welded structures, development of new experimental methods, and research to investigate the mechanism of fatigue and fracture phenomenon of steel products. The JWI-CIF^2 also holds exhibitions of large-scale test specimens and large-scale fracture surfaces to help visitors grasp the issues, and conducts cooperative study with customers, universities and research institutes.

2. Main Equipment of JWI-CIF^2

Verification of integrity by experiments using full-scale structures that approximate actual structures is indispensable. The general practice is to conduct a fracture mechanics evaluation using the properties obtained by a small-scale test. However, this fracture mechanics approach is based on the results of extensive experiments conducted in the past, and it is not clear whether it is directly applicable to newly developed steel materials and welding technologies. JFE Steel has developed and introduced new large-scale experimental equipment and conducted demonstration tests to promote the development and practical application of many new products including steel plates for shipbuilding and pipelines. In the past, developments with large-scale experimental equipment were conducted on separate sites, and now they have been consolidated in the new JWI-CIF^2 for research efficiency. The following presents an outline of the large-scale testing equipment owned by JWI-CIF^2.

2.1 Large-Scale Fracture Testing Machines for Heavy Steel Plates

Particularly in the shipbuilding field, the performance of thick plates against fracture is evaluated by conducting various large-scale tests to secure the integrity of the ship hull. The 80 MN tensile testing machine is a representative facility for large-scale tests. The most important feature of this facility is the largest class load capacity (80 MN) and largest distance between the two loading pins (distance between points of load: 10 m) in Japan. This equipment includes an impact device as a crack initiator and a heating/cooling system to control the temperature of the specimen for performing brittle crack propagation and arrest tests. Using this equipment, it is possible to perform brittle fracture experiments by applying loads equivalent to those of actual ships to large-scale heavy steel plate specimens and actual structural samples. This facility is mainly used for full-size fracture tests (large-scale structural model tests, ultra-wide duplex ESSO tests, etc.) in which the specimen size exceeds 2 000 mm.

The JWI-CIF^2 also has a 20 MN and 12 MN tensile testing machine, which are mainly used for tensile testing relatively small specimens, approximately 500 mm in size. The type of test is, for example, the deep notch test (brittle fracture initiation test), ESSO test (temperature-gradient type brittle fracture propagation/arrest test), CAT test (isothermal type crack arrest test), etc.

2.2 Large-Scale Testing Machines for Line Pipes

In the line pipe field, evaluations simulating the various risks that can occur through the time of pipeline construction to the service period are necessary. For

† Originally published in *JFE GIHO* No. 46 (Aug. 2020), p. 89−91

example, in buried pipelines in seismic hazard zones, buckling or rupture of the line pipe is possible due to large permanent ground deformation accompanying liquefaction or landslides. In order to evaluate integrity against fracture under those conditions, the JWI-CIF^2 developed a large-scale pipe bending machine which can bend full-scale line pipes and evaluate their bending capacity. This machine is the world's largest class pipe bending machine; maximum outer diameter of 48 inches (1 219 mm) and maximum length of 8 000 mm.

Buckling due to cyclic bending of line pipes is a risk when pipelines are laid by the reel-laying method, which is a typical pipelaying method for offshore pipelines. In the reel-laying methods, line pipes are reeled onto a drum at the port, and unwound from a reel at sea and laid down on the seabed. The JWI-CIF^2 has also developed a reel bending testing machine which can simulate cyclic bending deformation and conducted evaluation of integrity against buckling for reel-laying line pipes.

In order to evaluate the pressure resistance performance of line pipes more easily, the JWI-CIF^2 developed a ring expansion and ring collapse testing machines to measure the strength against internal or external pressure using ring-shaped specimens cut from the actual line pipe product. Use of these large-scale hydraulic testing machines makes it possible to measure yield stress with internal pressure and high pressure collapse resistance under external pressure in deep sea pipelines, etc.

2.3 Fatigue Testing Equipment

In the fatigue testing field, the JWI-CIF^2 has a total of five fatigue testing machines with maximum load capacities of 50 kN, 100 kN and 1 000 kN class. These testing machines can also be applied to fracture testing of structural specimens of steel structures that include welds as well as fatigue testing of materials. In order to ensure the reliability of welded steel structures, a new peening construction technology to suppress the initiation and propagation of fatigue cracks in welded joints was developed for the purpose of improving the fatigue life of joints, and created an environment where construction methods can be implemented and evaluated.

In materials which are to be used in gas storage tanks for LNG and other liquefied gases, service reliability under ultra-low temperature environments is required. In particular, fatigue damage due to sloshing of liquefied gases in addition to deformation and stress of ocean waves is also a concern in these tanks. Conventionally, fatigue performance of materials used in ultra-low temperature environments has been achieved by cooling small-scale test pieces, such as round-bar test pieces, in a specimen in a constant temperature bath. However, because of the limited size of the constant temperature bath and other problems, it was difficult to test the welded joints in which fatigue damage becomes a problem. To solve this problem, the JWI-CIF^2 fabricated a constant temperature bath and a cooling system which can deal with a test piece of a welded joint, and enabled verification of the fatigue fractures under an ultra-low temperature environment.

2.4 Fracture Sample Museum

In order to help customers understand fatigue and fracture phenomena and their evaluation techniques, the Fracture Sample Museum was established within the JWI-CIF^2. This museum displays large-scale fracture surface samples from fracture tests conducted on a large-scale structure replica of a mega-container ship. Furthermore, it also shows fracture surface samples from more general fracture tests (ESSO test, CTOD test, deep notch test and other small- and medium-scale fracture tests). By explaining the fracture phenomenon using real test samples in the exhibition room, we aim to have customers understand the philosophy of technological development and integrity evaluation technologies of JFE Steel more deeply.

In addition, there are meeting rooms where it is possible to view various large-scale testing machines from a close distance in the JWI-CIF^2. Using those facilities, we accelerated communications about generating ideas on the development of new products and new technologies with customers and researchers participating in cooperative studies.

3. Utilization of JWI-CIF^2

The following presents an example of the large-scale tensile testing machine utilization at JWI-CIF^2. **Photo 1** shows the external appearance of the 80 MN tensile testing machine. The 80 MN tensile testing machine is used in evaluations of the brittle crack

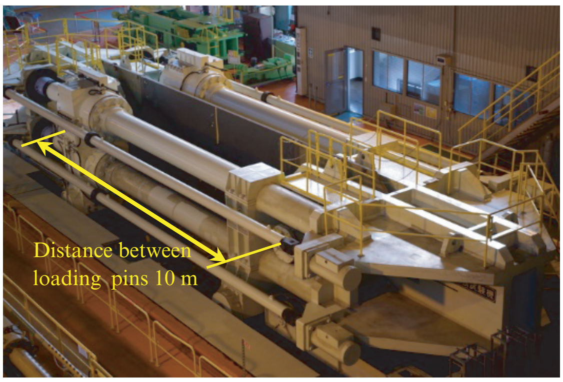

Photo 1 80 MN large-scale tensile testing machine

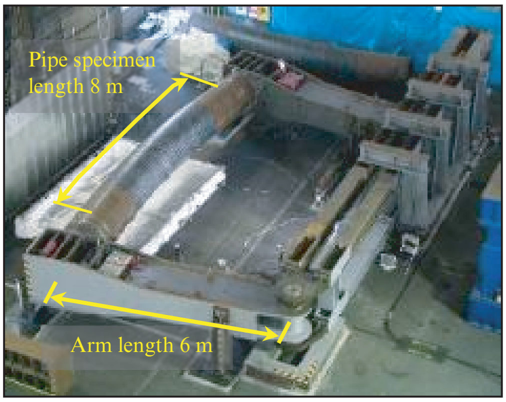

Photo 2 Pipe bending test by large-scale pipe bending machine

propagation/arrestability of heavy plates and welded structures, mainly for the shipbuilding field. Even if a brittle crack initiates in the hull and propagates over a long distance, it is necessary to prevent catastrophic destruction by stopping, i.e., arresting the crack during propagation in the middle of the hull. For this reason, the arrestability of brittle cracks is extremely important. Because the steel plates used in the tops of container ships have been getting thicker and recently reached 100 mm, a large test load capacity is required in tensile testing machines. Moreover, since the distance between the two loading pins is as long as 10 m, stress waves generated at the time of brittle crack initiation can be prevented from interfering with the test specimen, so that the arrestability of long brittle cracks can be evaluated under the same conditions as in actual ships. JFE Steel is contributing to the safe navigation of ships by the development of a structural arrest technology [1] and extremely thick steel plates with high strength and high arrestability [2] by using the large-scale tensile test machine at the JWI-CIF^2.

Next, **Photo 2** shows the large-scale pipe bending machine used in evaluations of the bending capacity of line pipes. In a buried pipeline, there is a risk that the pipe is largely deformed by ground movement, such as earthquake-related fault movements, landslides and permanent ground deformation accompanying liquefaction, by ground deformation induced by repeated melting and frost heaving in discontinuous frozen ground zones, etc.. Line pipes should be prevented from buckling and fracturing in such harsh environments. JFE Steel developed HIPER™, which has a higher deformation capacity (strain capacity) than that of conventional line pipes, and clarified that the strain capacity of HIPER is more than two times higher than that of conventional line pipes by a comparable study using the large-diameter pipe bending machine [3]. The high integrity of HIPER was demonstrated by these test results, leading to the adoption of this line pipe in a large number of pipeline projects in seismic hazard zones and discontinuous frozen ground zones.

4. Conclusion

Since the JFE Welding Institute — Center for Integrity against Fatigue and Fracture was opened in February 2019, the JWI-CIF^2 has carried out many technical exchange meetings and cooperative studies with other organizations and outside researchers by utilizing substantial test facilities and observation facilities. In the future as well, the JWI-CIF^2 will continue to contribute to the safety and security of society through the development of new value-added steel products and the provision of high-level evaluation technologies for steel structures.

References

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