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SMART100 Fuel Assembly Mechanical Test at End of Life

Juyeob Yoon [a*], Kyounghong Kim [a], Dongguen Ha [a], Yoonho Kim [a]
[a]*Kepco Nuclear Fuel, #242, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 305-353, Korea*
[*]*Corresponding author: yoonjy@knfc.co.kr*

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1. Introduction

SMART(System-integrated Modular Advanced ReacTor) 100 is an advanced small sized nuclear power reactor, which adopts various inherent and passive design feature to achieve enhanced safety and improved economics compared to commercial nuclear power plants. As shown in Fig 1, SMART100 fuel assembly consist of removable top nozzle, each grid, lower pressure drop bottom nozzle, guide tube and 17×17 array fuel rod. This fuel assembly is designed to be satisfied with 0.3g seismic criterion at beginning of life(BOL) and end of life(EOL) conditions. The structural integrity of fuel assembly is evaluated through the finite element method(FEM). However, the mechanical tests of fuel assembly shall be preceded to verify mechanical characteristics of the finite element model. Thus, in this study, to obtain the SMART100 fuel assembly static and dynamic characteristics such as stiffness and impact force, the test procedure and test result are described with respect to lateral mechanical test of SMART100 fuel assembly at EOL condition[1].

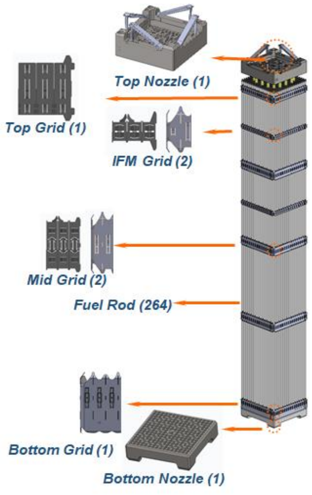


Fig. 1 SMART100 fuel assembly

2. Test

2.1. Test Equipment

SMART100 Fuel assembly vibration tests have been performed in TOFAS-A. TOFAS-A is a test facility built in KNF for FA-wise tests such as static and dynamic tests. It is possible to identify the fuel assembly mechanical characteristics such as natural frequency and bending stiffness of fuel assembly in air condition by using TOFAS-A. As shown in Fig 2, this facility can mount fuel assembly that reflected in core boundary condition on the test bed[1].

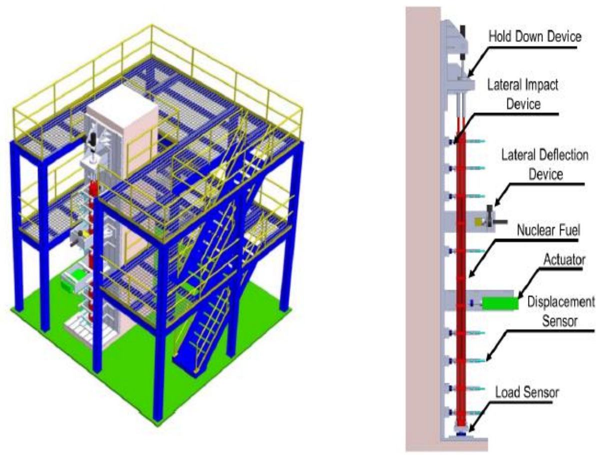


Fig. 2 TOFAS-A facility configuration

The vertical test bed consists of a thick steel plate and a concrete structure which are capable of installing various instruments for fuel assembly. The general specification of TOFAS-A is summarized in Table 1.

Table 1. General specification of TOFAS-A

TOFAS-A
- 6m × 6m × 6.5m Size (3 Stories)
- 1.5m × 1.5m × 6.5m Reinforced Concrete
- 90mm Steel Backboard
- 6 Rail Ways for Movable Measurement
- 35kN Hold Down Force
- 4kN Lateral Deflection Force

2.2. Test Configuration

The schematic of SMART100 fuel assembly, instrument, mechanical jack, measurement position, and structure are shown in Fig. 3 ~ 4 as mechanical test in air condition. Displacement were applied to the 3rd (central, 2nd mid) grid of the fuel assembly and the output of load cell and linear variable differential transformers (LVDTs) were recorded on the hard disk according to the test.

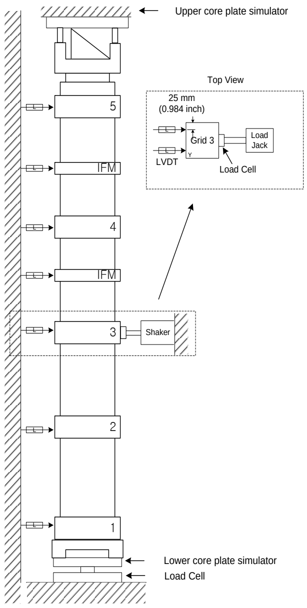


Fig. 3. Schematic of lateral stiffness test

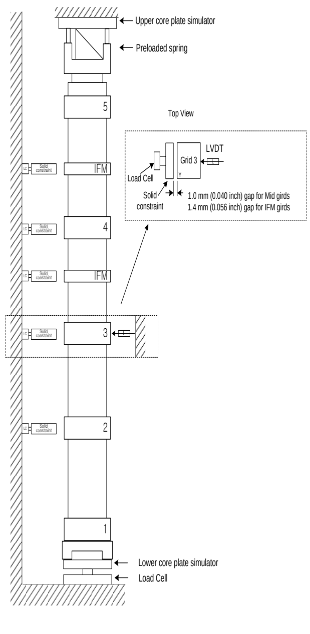


Fig. 4. Schematic of lateral impact test

2.3. Test Method

2.3.1 Lateral Stiffness Test

As shown in Fig. 3, SMART100 fuel assembly was positioned vertically in the test stand and restrained at the top and bottom nozzles with core plate simulators typical of reactor support conditions. The fuel assembly was axially pre-loaded to simulate EOL hot condition. 14 LVDTs were used; 2 LVDTs were placed at every grid location. As shown in Table 3, the loads were applied to grid 3 by mechanical jack, mounted in series with a load cell.

2.3.2 Lateral Impact Test

The schematic of lateral impact test is shown in Fig. 4 This test environment and conditions are the same as the lateral stiffness test. At the lateral impact test, the LVDTs was utilized at 3rd grid to monitor the displacement of the fuel assembly mid-grid. Three solid constraints were placed at the three mid grid locations, and two solid constraints were placed at the 2 IFM positions. Load cells were placed in series with the solid constraints to obtain impact forces and duration times. The test method and initial condition are presented in Table 4 below.

Table 3. Lateral stiffness test

Test Method	Displacement amount	Measurement variables
Pull & Push	(-30 ~ 30) mm	• Lateral load • Lateral grid displacement

Table 4. Lateral impact test

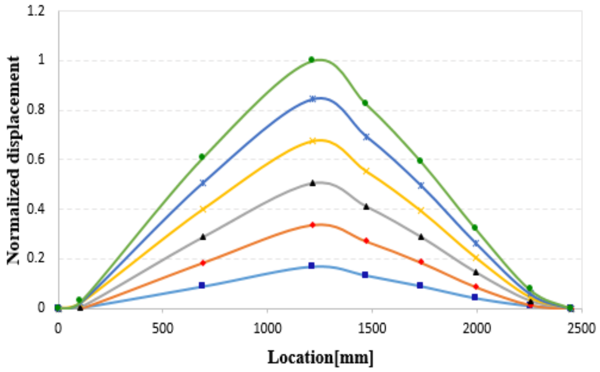
Test Method	Initial Displacement	Measurement variables
Magnetic release	5 ~ 20mm1)	• Lateral impact load • Lateral grid displacement

1) Increase initial displacement in 5mm increments from 5mm until maximum initial displacement of 20mm

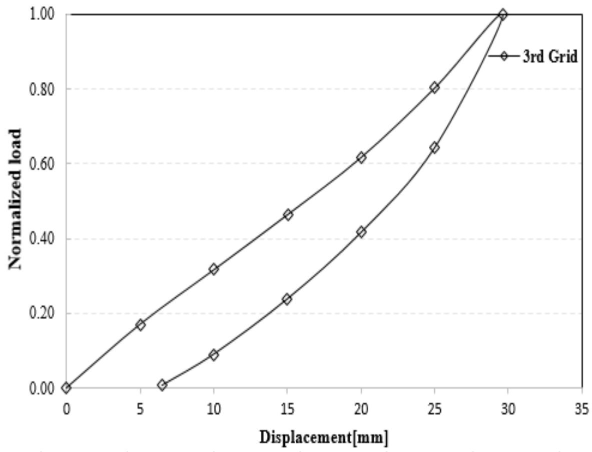
2.4. Test Result

2.4.1 Lateral Stiffness Test

The lateral stiffness characteristics of SMART100 fuel assembly were obtained from tests conducted in air at room temperature. The lateral load versus displacement characteristics of the fuel assembly and displaced shape along the fuel assembly for loads independently applied at grid 3 is displayed in Fig. 5. Here, the normalized values are defined as a ratio between the corresponding value and maximum value. The load-displacement characteristics were non-linear, mainly due to the fuel rod slip. The assembly did not return to its original position when unloaded due to the frictional forces of fuel rods.



a) Displaced shape



b) Load-displacement curve

Fig. 5. Displaced shape and lateral load vs displacement

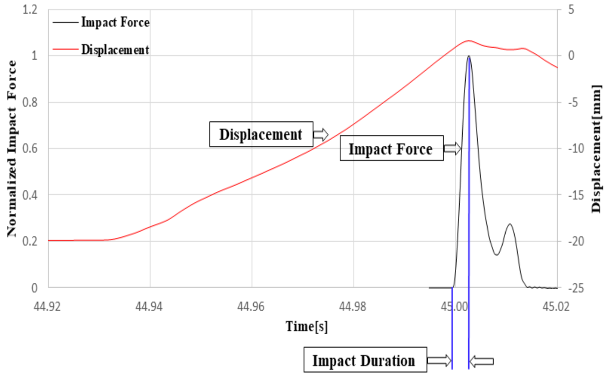


Fig. 6. 3rd grid impact force(initial displacement : 20mm)

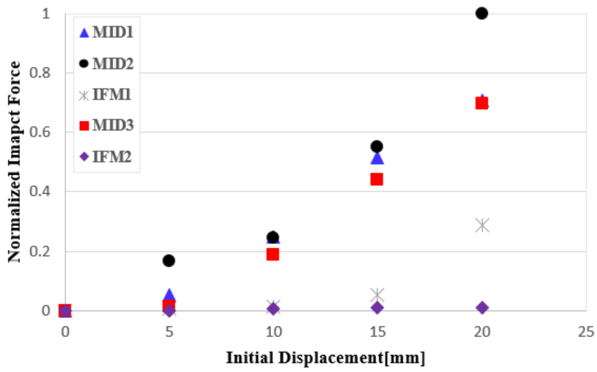


Fig. 7. Impact force of all grids

2.4.2 Lateral Impact Test

The lateral impact characteristics of SMART100 fuel assembly were obtained from tests conducted in air at room temperature. The testing procedure consisted of displacing the 3rd structural grid of the fuel assembly a predetermined amount, relative to its initial equilibrium position. The fuel assembly was then released suddenly and allowed to impact against a solid constraint. A typical trace of the fuel assembly mid-grid impact motion of grid 3 for an initial lateral displacement of 20 mm is given in Fig. 6. The initial fuel assembly central grid displacements versus the impact forces measured at the five central structural grids when impacted to solid constraints are displayed in Fig. 7. The impact forces at each location increased fairly with respect to the initial central grid displacement with grid 3 (mid grid 2) when experiencing large impact forces. In Fig. 6 ~ 7, the normalized impact force is defined as the ratio between the corresponding value and maximum value.

3. Conclusion

In this study, the lateral mechanical tests of the SMART100 fuel assembly were performed to find out the dynamic characteristics, and the test procedures, method and results were describes. In the near future, a finite element model for evaluation of the fuel assembly integrity will be developed and adjusting parameter through the test results such as stiffness and grid crush values.

REFERENCES

[1] J. Y. Yoon, SMART100 Fuel Assembly Vibration Test at End of Life, Transactions of the Korean Nuclear Society Spring Meeting, 2024.