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Development of Friction-Type EQS for APR1400 NPP

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ABSTRACT

This paper presents the development of the friction-type Eradi-Quake System (EQS) for APR 1400 NPP. Consisting of a sliding bearing assembly with damping and mass energy regulator spring, EQS is the seismic isolation system to be applied widely to industrial facilities. For the nuclear power plant structure, the seismic isolation device needs to have higher performance, durability, and reliability than a device for industrial structures. First, the standard characterization test for evaluating the performance of EQS was conducted, and ways to improve the performance were identified. The material test for the sliding material and MER-Spring as mass energy regulator spring was performed to verify the reliability and durability, respectively, of the components of EQS: friction test, wear resistance test, aging test, ozone resistance test, wet test, creep test, and compression test. This research showed the improvements in the performance of the EQS seismic isolator, a spring recovery-type friction method development for the improvement of seismic safety in nuclear power plants, and described the results of various verification tests for the evaluation of improved performance.

INTRODUCTION

Nowadays, there is growing clamor for the improvement of seismic safety in structures because of the increasing frequency of earthquake occurrence and its growing scale. The improvements of seismic safety in structures can be divided into seismic design and seismic isolation design. Seismic design involves raising the resistance to seismic load by constructing the structure itself strongly; seismic isolation design is based on the concept of reducing the load transferred to the upper part using the method for the absorption of seismic load by a seismic isolator, which is transferred from the ground, by inserting a seismic isolator between the structure and the ground. The design to introduce the seismic isolator was performed in particular structures only due to the limitation of seismic design.

This research showed the improvements in the performance of the EQS (Eradi-Quake System) seismic isolator, a spring recovery-type friction method developed for the improvement of seismic safety in nuclear power plants, and described the results of various verification tests for the evaluation of improved performance.

DESIGN OF THE EQS SEISMIC ISOLATOR

EQS seismic isolator is one of the seismic isolators widely used in structures and bridges; its shape is shown in Fig. 1.

The EQS device consists of top plate, lower plate, bearing block, friction material adhered to the bearing block, MER-Spring, which has the recovery force, and Polytro Disk, which supports vertical load and accepts rotation displacement. In the existing EQS seismic isolator, the non-recovery displacement region – wherein the horizontal load is constantly maintained in the vicinity of 0mm displacement in case of repeated history behavior – can be formed.

This is caused by the phenomenon wherein MER-Spring – which receives the compression force – receives the compression again before recovering its original length. To remove such non-recovery displacement, and to improve the performance of MER-Spring, prestress is adopted in MER-Spring; the shaft applied to MER-Spring is improved to accept more displacements than the existing EQS seismic isolator. Fig. 2 shows the shape of the MER-Spring system after the improvement.
The displacement acceptance capability is improved by reducing the shaft's insertion length according to the displacement by dividing the shaft into two stages; the interference between shafts – which can occur when MER-Spring is compressed – is minimized. To evaluate the improved MER-Spring performance, the compression recovery test was performed, and the result was compared with that of the existing MER Spring. As a result of the test, non-recovery displacement did not nearly occur due to the adoption of prestress technique as shown in Fig. 3.

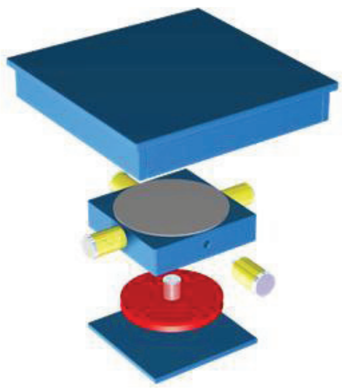


Figure 1. Existing EQS Shape

Figure 2. Improved MER-Spring System

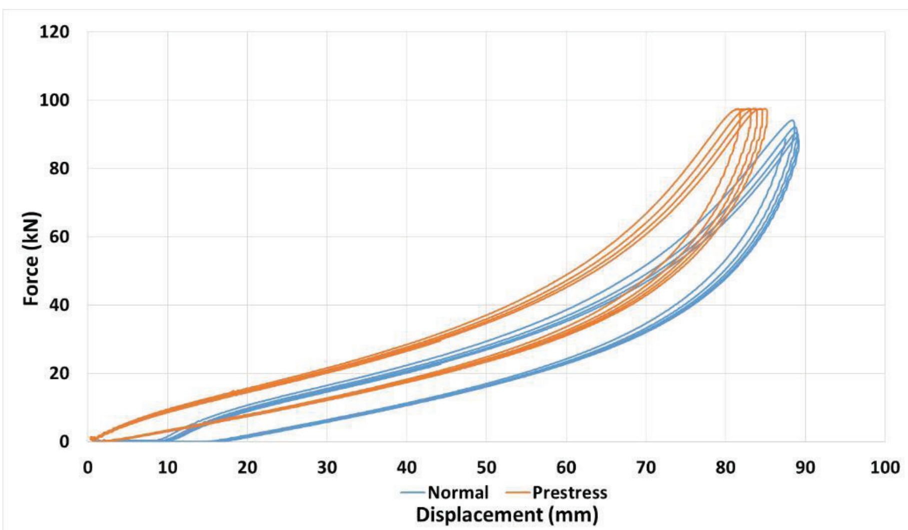


Figure 3. Comparison between the compression recovery test results

To improve the performance of friction material, a friction material with high strength and good friction performance was applied. The wear test was conducted to evaluate the performance of friction material, and its results are illustrated in Fig. 4. The friction coefficient in the 1st cycle was 0.062, and that in the 100th cycle was 0.042; 32% damping in friction force occurred during 100 cycles. This shows the improvement in performance compared with the existing friction material. After the wear test, the shapes of the friction materials in the existing EQS and improved EQS could be identified with the naked eye, and the wear amount in the improved friction material was evaluated to be small (Figs. 6 and 7).

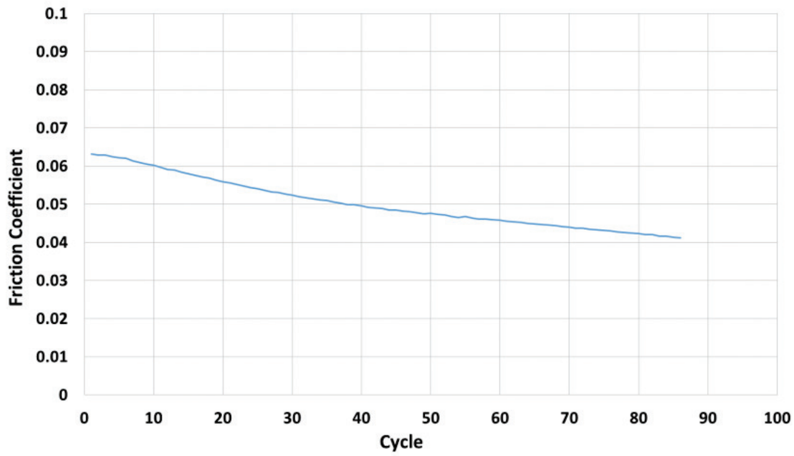


Figure 4. Variations of Friction Coefficients According to Test Cycles

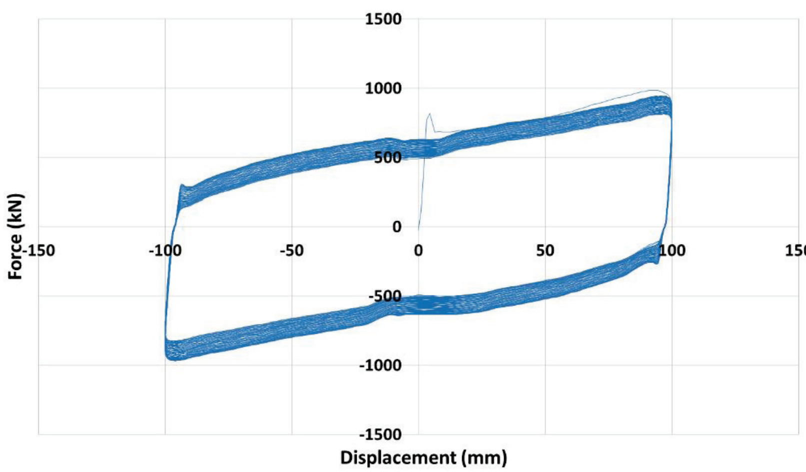


Figure 5. Hysteresis Curve of Friction Material Wear Tests

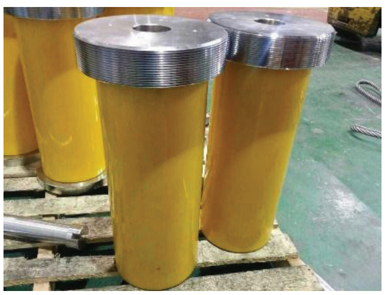
Fig. 6. Existing Friction Material (100-cycle)

Fig. 7. Improved Friction Material (100-cycle)

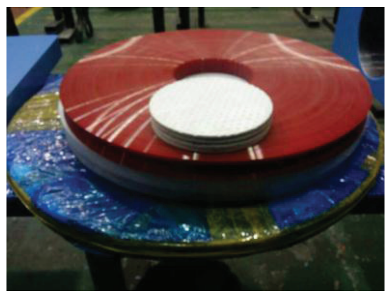
Reflecting the improvement matters above, the EQS seismic isolator was designed and manufactured with the following characteristics: 10,000kN vertical load, 2.3 sec aim frequency, and ±224mm design displacements. The design characteristics values of this EQS seismic isolator are shown in Table 1, and its manufacturing process is presented in Fig. 8.

Table 1: Material Properties of the EQS Seismic Isolator

Dead Load	Q_d	K_2	K_{eff}	Displacement	Period
10,000kN	820kN	3.94kN/mm	7.60kN/mm	±224mm	2.30 sec



(a) MER-Spring

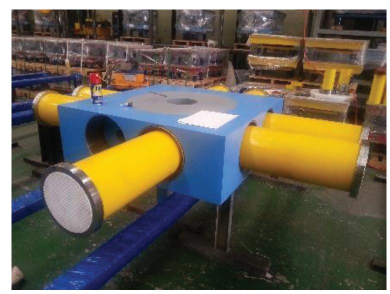


(b) Polytron Disk

(c) Top Plate

(d) Bearing Block

(e) Low Plate



(f) Bearing Block Assembly

Figure 8. EQS Manufacturing Process of the EQS Seismic Isolator

PERFORMANCE EVALUATION TEST

To evaluate the performance of the improved EQS seismic isolator, dependency tests were performed on velocity, displacement, and surface pressure. The dependency tests can identify the velocity & scale of seismic wave and characteristics changes in the device according to the loaded weight.

The scale of the improved EQS seismic isolator was $2{,}328mm \times 2{,}328mm \times 555mmm$; only the test for 180mm, which corresponds to 80% of the maximum design displacement, was performed because 100% design displacement was unacceptable due to the environmental condition of the domestic test equipment. The test conditions are as follows:

Table 2: Test Conditions of the EQS Seismic Isolator

Test Type	Test Condition	Remarks
Basic Characteristics	-	Vertical Load: 10,000kN Test Velocity: 100mm/sec Test Displacement: ±180mm
Surface Pressure Dependency	15MPa, 20MPa, 25MPa	Test Velocity: 100mm/sec Test Displacement: ±180mm
Displacement Dependency	50mm, 100mm, 150mm, 180mm	Vertical Load: 10,000kN Vertical Load Test Velocity: 100mm/sec
Velocity Dependency	5mm/sec, 20mm/sec, 100mm/sec	Vertical Load: 10,000kN Test Displacement: ±180mm

Results of the Basic Characteristics Test

To evaluate the basic performance of the EQS seismic isolator, tests were performed at 10,000kN vertical load, ±180mm displacements, and 100mm/sec velocity. The test results are shown in Fig. 9 and compared with the design values

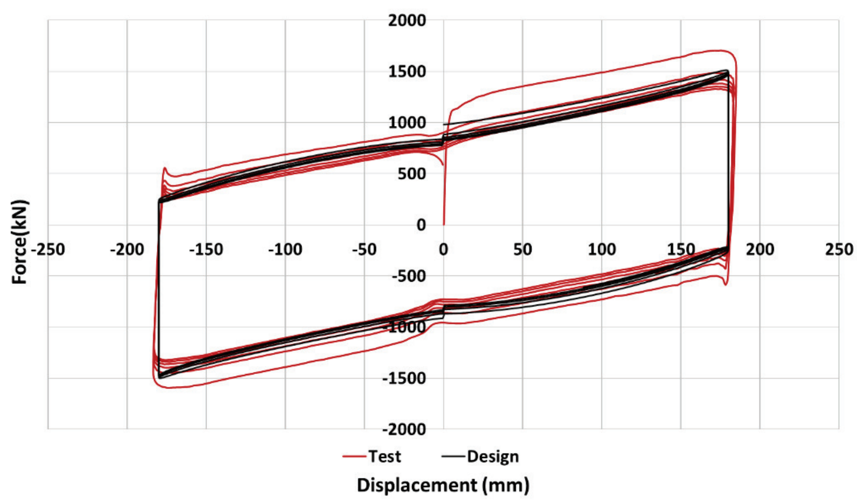


Figure 9. Load-Displacement Hysteresis Curve of Design-Test Results

Table 3: Test Conditions of the EQS Seismic Isolator

Type	Design	Test	Tolerance
Q_d	820 kN	825 kN	-1%
Friction Coefficient	0.082	0.082	0%
EDC	618.929 kN.mm	613,020 kN.mm	1%
K_{eff}	8.08 kN/mm	7.683 kN/mm	5%
Period	2.3 sec	2.3 sec	0%

As a result of the test, the load history curve showed that the design values and test values were nearly the same. Under ±180mm displacements, EDC was 613,020kN.mm and k_{eff} was 7.683kN/mm; under the same condition, EDC of the design value was 618,929kN.mm, and k_{eff} was 8.08kN/mm. In terms of tolerances in the characteristics' values, the tolerance of EDC was 1%, and that of effective stiffness was 5%. In other words, tolerances were deemed to occur within 5% compared with the design values.

Results of the Surface Pressure Dependency Test

To identify the characteristics of the EQS seismic isolator according to surface pressure, tests were performed by varying the scales of vertical loads applied to the device. Test displacement of 180mm – which is 80% of the design displacement of 224mm – was adopted; the scale of surface pressure was increased by 5MPa from 15MPa to 25MPa.
As a result of the test, yield loads showed an increasing trend – 678kN→825kN→838kN – as the surface pressure increased; yield load recorded a 123% increase when the maximum vertical load reached 166%. The small increase rate of yield load compared with the increase of vertical load was attributed to the decrease of friction coefficient. In particular, friction coefficients were found to have decreased to 0.090, 0.082, and 0.067 when the surface pressures were increased to 15MPa, 20MPa, and 25MPa, respectively.

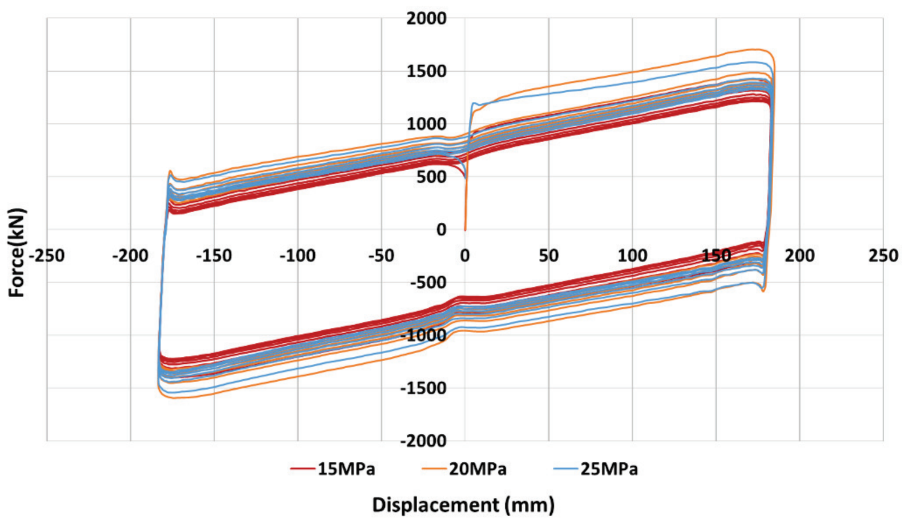


Figure 10. Results of the Surface Pressure Dependency Test (Load-Hysteresis Curve)

Table 3: Results of the Surface Pressure Dependency Test

Test Conditions	EDC Test Values (kN.mm)	K_{eff} Test Values (kN/mm)
10 MPa	471,658	6.881
20 MPa	613,020	7.683
25 MPa	604,099	7.903

Results of the Displacement Dependency Test

To evaluate the EQS seismic isolator according to displacement, tests were performed by varying the test displacements in the device.

The test displacements were given in 4 steps: 50mm, 100mm, 150mm, and 180mm; the test results of the device are presented in Fig. 11. As shown in the test results, yield strength and secondary stiffness showed a similarity even when the displacements of the seismic isolator were increased. By adopting prestress in the MER-Spring system, the non-recovery displacement occurrence region was found to have decreased.

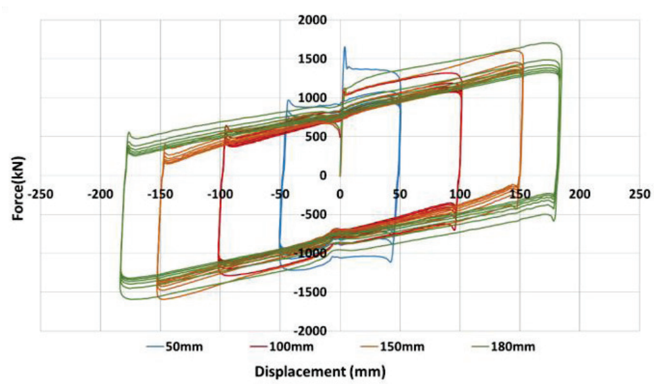


Figure 11. Results of the Displacement Dependency Test (Load-Hysteresis Curve)

Table 3: Results of the Displacement Dependency Test

Test Conditions	EDC Test Values (kN.mm)	K_{eff} Test Values (kN/mm)
50 mm	125,166	19.880
100 mm	309,020	11.527
150 mm	478,515	9.125
180 mm	613,020	7.683

Results of the Velocity Dependency Test

To evaluate the characteristics of the EQS seismic isolator according to velocity, tests on velocity were performed by classifying into low speed and high speed. The results are shown in Fig. 15. The variations of EDC and effective stiffness according to the increase in velocity were not big. This means that the variations in the dynamic characteristics of the improvement-type friction material used are small.

Table 4: Results of the Velocity Dependency Test

Test Conditions	EDC Test Values (kN.mm)	K_{eff} Test Values (kN/mm)
5 mm/sec	638,314	7.743
20 mm/sec	635,787	7.717
100 mm/sec	613,020	7.683

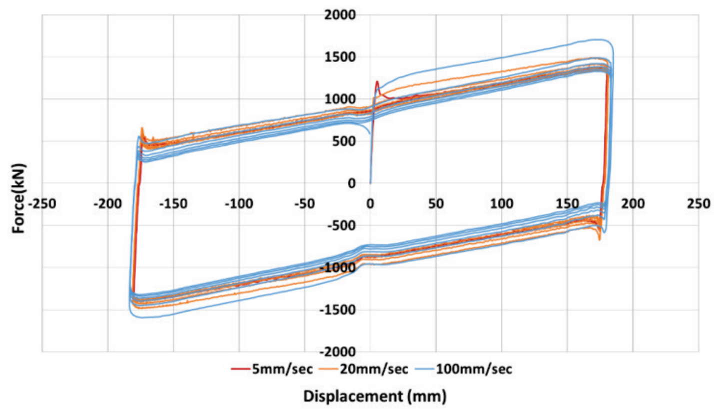


Figure 11. Results of the Velocity Dependency Test (Load-Hysteresis Curve)

CONCLUSION

This research conducted performance evaluations of the EQS seismic isolator, which was developed to improve seismic performance in nuclear power plants. Matters for performance improvement in the EQS seismic isolator are as follows:

1) Non-recovery displacement occurrence was minimized by applying the prestress technique to the MER-Spring system and improving it to reduce the non-recovery quantity in the existing EQS.
2) By adopting a new plastic series material, the performance against wear and damages in the friction material was improved based on more than 100 times' repeated tests.

The performance was evaluated by conducting the basic characteristics test and various dependency tests; for this, a finished EQS product to which the improved material was applied was manufactured. The results of the performance evaluation test showed excellent yield load, friction coefficient, EDC, and effective stiffness, which are the basic characteristics, with 0~5% errors compared with the design. Likewise, dependencies on surface pressure, displacement, and velocity were found to be low.

ACKNOWLEDGMENT

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