STUDY ON THE EFECT OF THE CHARACTERISTIC PARAMETER TO IMPROVE THE SEISMIC MARGIN OF FUEL ASSEMBLY

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ABSTRACT

In this paper, the effect of the characteristic parameter is studied to improve the seismic margin of fuel assembly. HIPER16 fuel assembly in the reactor vessel internal of APR+ is considered. The fuel assembly in the seismic model of reactor vessel internal is simulated with the beam and mass element. The characteristic parameter of mass element is not considered, but that of beam element is considered. The bottom and top of fuel assembly is simulated with the rotation spring to consider the boundary condition. The rotation spring rate is considered. The spring-gap element is used to simulate the impact between fuel assemblies. The stiffness and coefficient of restitution of impact between spacer grids of fuel assemblies are considered. The flow damping ratio is used to improve the seismic margin of fuel assembly after the effect of end-of-life condition should be considered. The flow damping ratio is also studied to improve the seismic margin of fuel assembly. The seismic analysis of reactor vessel internal is analyzed using the nonlinear dynamic analysis so that the seismic load is considered. The analysis model was excited with increased level of safe shutdown earthquake load up to 1.2 times. To improve the seismic margin of fuel assembly, the method to change the characteristic parameter such as the moment of inertia, the rotation spring rate and the through-grid stiffness should be developed.

1. Introduction

After NRC issued the Information Notice 2012-12[1], the safety margin of a fuel assembly has decreased by considering the effect of an end-of-life (EOL) condition. Recently to improve the safety of nuclear power plant, Evaluation for an increase of a seismic load is needed. To improve the safety margin of a fuel assembly under a seismic condition, the mechanical design of a fuel assembly may be changed. Matthews et al[2] introduced new fuel assembly design and the new methodology describing a space grid with a nonlinear deformation to maintain sufficient margins to grid crush strength for the increased external excitations such as a seismic and loss-of-coolant-accident loading. The safety margin of a fuel assembly is determined by the ratio of the impact force to the grid crush strength. In this paper, the effect of characteristic parameters of fuel assembly on the impact force by the dynamic load such as a seismic and a loss-of-coolant-accident (LOCA) load is studied to determine a purpose for change of fuel assembly mechanical design.

2. Seismic analysis of reactor vessel internals

2.1 Analysis method

Figure 1 shows the seismic analysis procedure of reactor vessel internals. First, the seismic responses of the reactor containment building and RCS (Reactor Coolant System) are calculated by a RCS seismic analysis to determine the input of the RVI model. The horizontal and vertical motions of the RV (Reactor Vessel) flange are used as the input of a horizontal and vertical RVI models, respectively. The seismic analyses of RVI are performed separately for the horizontal and vertical directions. The RVI models are developed for two horizontal models and one vertical model to account for the structural characteristics and their responses more effectively.

A detailed core horizontal analysis using the results of a horizontal RVI analysis is performed to obtain the response of fuel assemblies to seismic excitation. The maximum responses from the detailed core analyses are used to evaluate the structural integrity of fuel assemblies. Especially the impact load on a fuel assembly of a horizontal analysis is the key parameter for the safety margin of fuel assembly under a seismic load. So, the results of a detailed core horizontal analysis are considered.

Figure 2 shows a detailed core model. The mass-beam element is used for a fuel assembly. The spacer grid nonlinear gap elements are modified to consider the proper peripheral fuel assembly row model impacting the core shroud for the new model. Each spacer grid utilizes a dual load path representation which accounts for both one-sided and thru-grid impact response loadings. Especially the impact load on a fuel assembly of a horizontal analysis is the key parameter for the safety margin of fuel assembly under a seismic load.

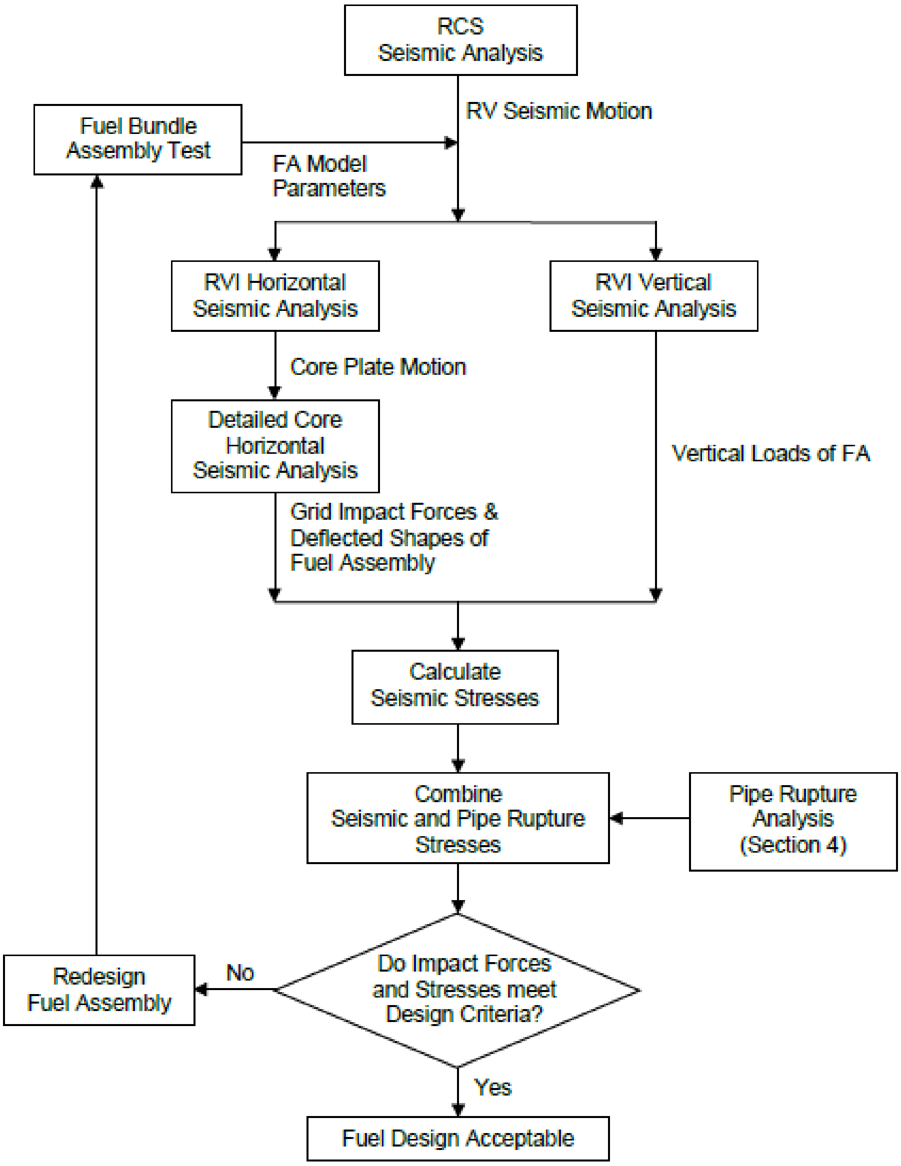

Fig. 1 Seismic analysis procedure

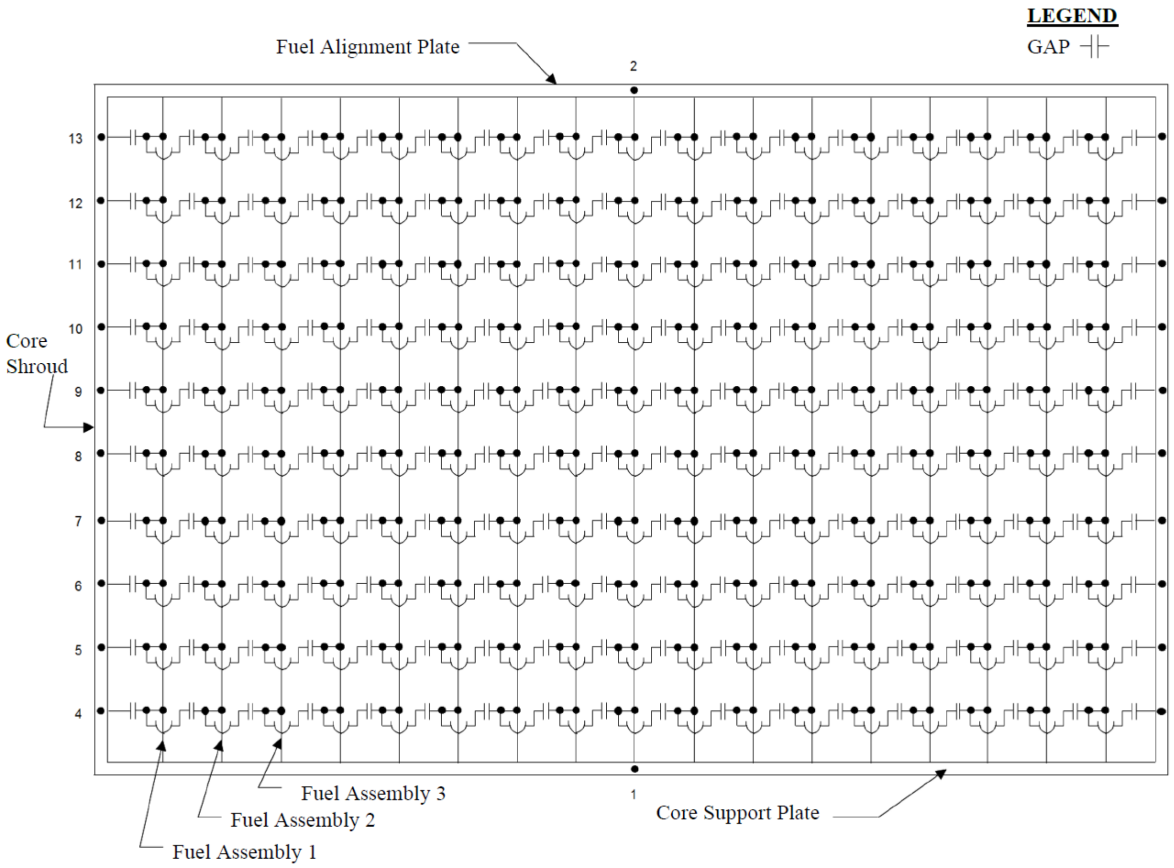

Fig. 2 Detailed core model

2.2 Characteristic parameter of fuel assembly

The fuel assembly model used in a seismic horizontal analysis of reactor vessel internals is modeled by a mass-beam element. Masses and evaluations of mass elements are determined by a fuel assembly design. These parameters are not considered in this paper. A flexural rigidity of beam elements is the same and determined by the comparison between the test and the analysis results. It is affected by a natural frequency and a deformation of a fuel assembly.

A top nozzle and a bottom nozzle are mounted at fuel alignment plate and a lower support structure. The behavior of a top nozzle and bottom nozzle of a fuel assembly is described by the rotational springs. The characteristic parameter of the rotational springs is a rotational spring rate.

The impacts between fuel assemblies and fuel assembly-to-core shroud are described by the linear springs. A fuel assembly is impacted by a fuel assembly or a core shroud in one-sided or through-grid method as shown in Figure 2. A one-sided grid stiffness and a through-grid stiffness are the parameter for the impact load of a fuel assembly under a seismic load. Especially, a through-grid stiffness is the major parameter. A grid stiffness is changed by the grid spacer design and a contact between a rod and a grid spacer.

The complex geometry of a grid spacer makes the dissipation of energy during the impact of a spacer grid. The coefficient of restitution is used for the dissipation of energy during the impact of a spacer grid.

The critical damping value of 4 percent is used for the RVI components. This value is consistent with Regulatory Guide 1.61. The additional damping caused by submerged condition of the RVI is ignored for the conservatism. Also, the critical damping of fuel assembly is used for detailed core model. These data are taken from the pluck vibration test and Flow water damping test. Proportional mass and stiffness damping coefficients are applied to the RVI components and fuel assembly.

2.3 Basic conditions

Figure 3 shows the analysis model of a fuel assembly. A fuel assembly is modeled as uniform beam with rotational springs at its ends to account for reactor end condition which are neither fixed nor pinned. The mass of the fuel assembly is concentrated at mass points located coincident with the space grids.
This model is consist of concentrated mass, spring stiffness, upper and lower rotational spring coefficient, coefficient of restitution (COR), damping of fuel assembly, spacer grid stiffness. So, these characteristic parameters consisting for fuel assembly model are used in this sensitivity study.
The RCS analyses are conducted for several foundation conditions. One soil case and one rock case which show the maximum impact force on a fuel assembly are determined to consider the effect of a foundation condition.

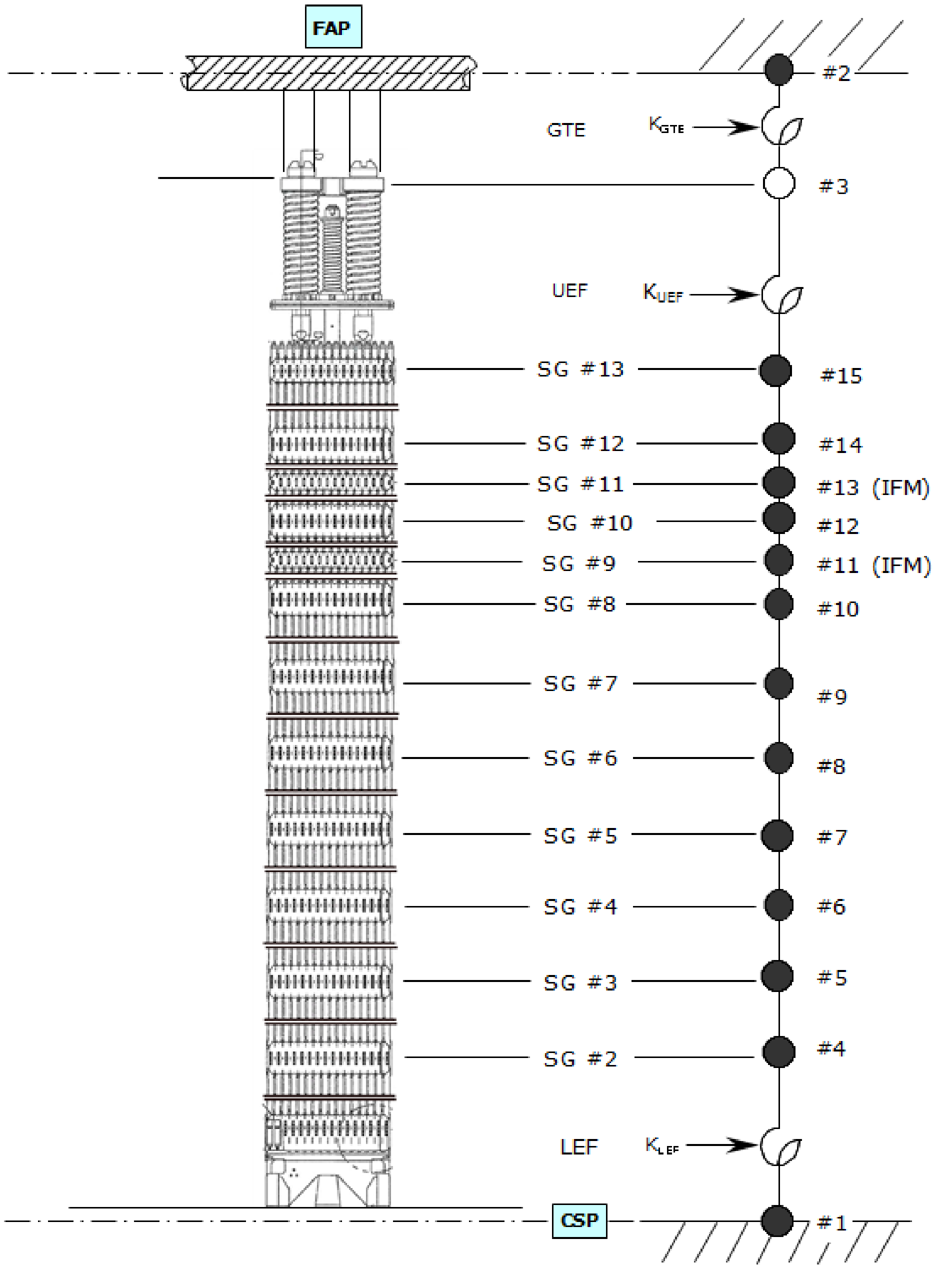

Fig. 3 Fuel assembly model schematic diagram

3. Parameter study

The characteristic parameters of fuel assembly model such as a flexural rigidity, a rotational spring rate, grid stiffness, a coefficient of restitution, and a flow damping ratio are considered to study the effect on the maximum impact force under a seismic load. A seismic load level for dominant parameters is also considered because of a nonlinearity of a seismic analysis.

3.1 Fuel assembly flexural rigidity

A fuel assembly flexural rigidity is changed with 20% increase and decrease. In these cases, a rotational spring rate of a top and a bottom nozzle is not changed. The natural frequency of a fuel assembly is 7.2% increase and 11.76% decrease by 20% increase and decrease, respectively. Fig. 4 shows the maximum impact force with the change of a fuel assembly flexural rigidity. The impact force decreases with an increase of a fuel assembly flexural rigidity. The effect of a flexural rigidity increase is similar for a soil case and a rack case. The effect of a flexural rigidity decrease for a rack case is lower than that for a soil case.

3.2 Rotational spring rate of top and bottom nozzle

Rotational spring rates of a top and a bottom nozzle are changed with a 20% increase and decrease. The natural frequency of a fuel assembly is 3.3% increase and 2.0% decrease with 20% increase and decrease of an upper rotational spring rate and 2.6% increase and 2.6% decrease with 20% increase and decrease of a lower rotational spring rate. Figure 5 and 6 show the effect of an upper rotational spring rate and a lower rotational spring rate. The effect of a spring rate is negligible.

Figure 7 shows the effect of a flexural rigidity and spring rate. The natural frequency of a fuel assembly is 4.5% increase and 4.5% decrease with 20% increase and decrease of a flexural rigidity and a rotational spring rate. 10% decrease of the maximum impact force with a flexural rigidity and about 3% change of the maximum impact force with a spring rate show. But a change of both a flexural rigidity and a spring rate affects about 20% change of the maximum impact force.

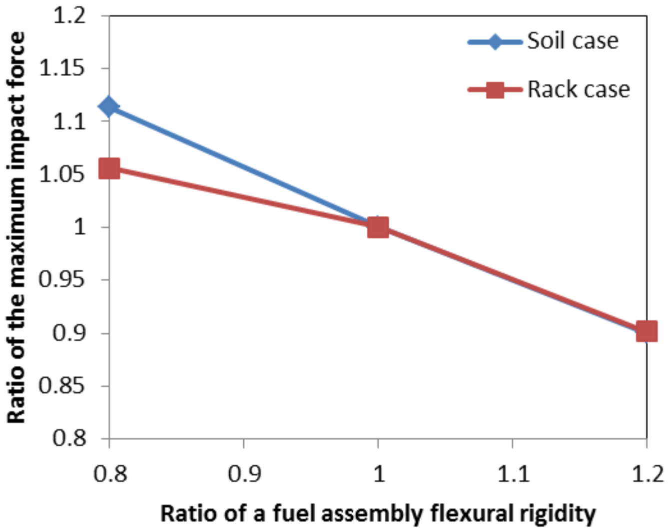

Fig. 4 The maximum impact force with a fuel assembly flexural rigidity

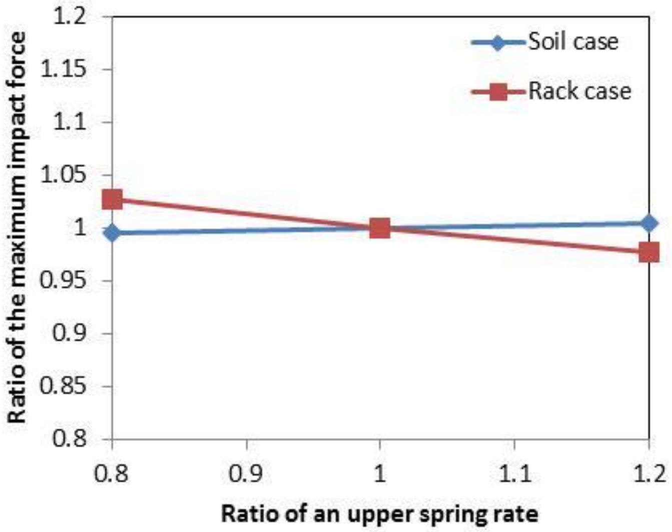

Fig. 5 The maximum impact force with an upper spring rate

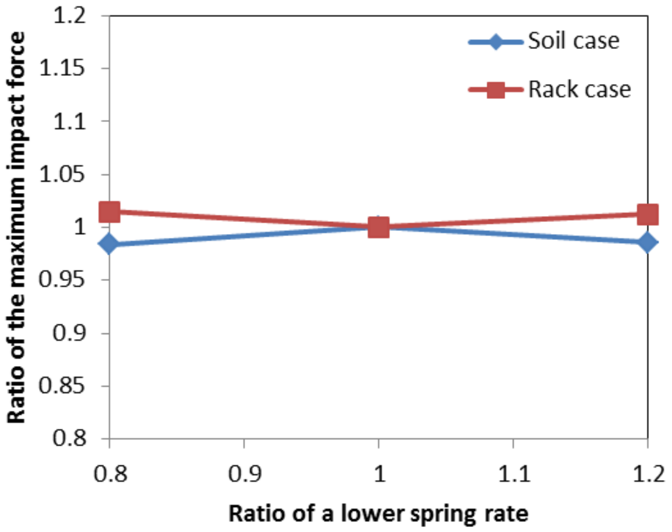

Fig. 6 The maximum impact force with a lower spring rate

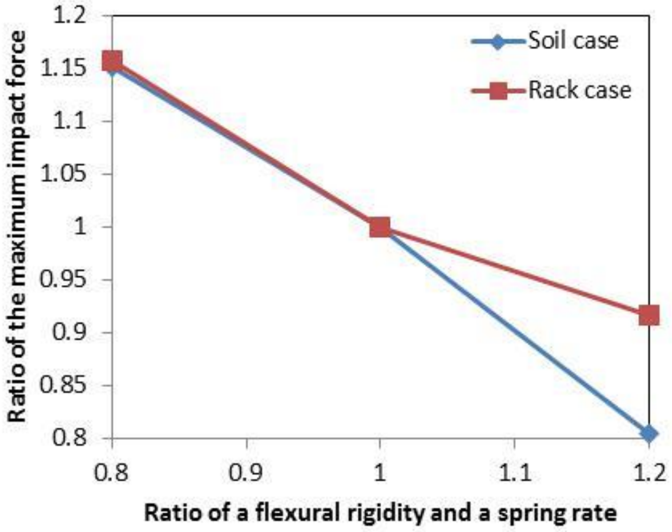

Fig. 7 The maximum impact force with a flexural rigidity and a spring rate

3.3 Through-grid stiffness

Figure 8 shows the maximum impact force with a through-grid stiffness. The maximum impact force increases with a through-grid stiffness. Due to a nonlinearity of a seismic analysis, the increase ratio of the maximum impact force is lower than the increase ratio of a through-grid stiffness. A through-grid stiffness is one of the dominant parameter.

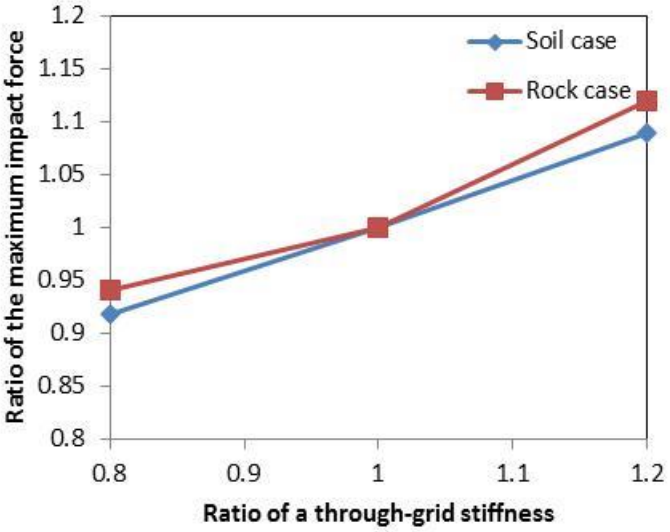

Fig. 8 The maximum impact force with a through-grid stiffness

3.4 Coefficient of restitution

Coefficient of restitution is the factor to consider energy dissipation during impact. Figure 9 shows the maximum impact force along with coefficient of restitution. Due to the coefficient of restitution, 2~3% change of the maximum impact force appears. The coefficient of restitution is one of the factor improve the impact force, but is not dominant. Those results are due to the through-grid impact cases between fuel assemblies.

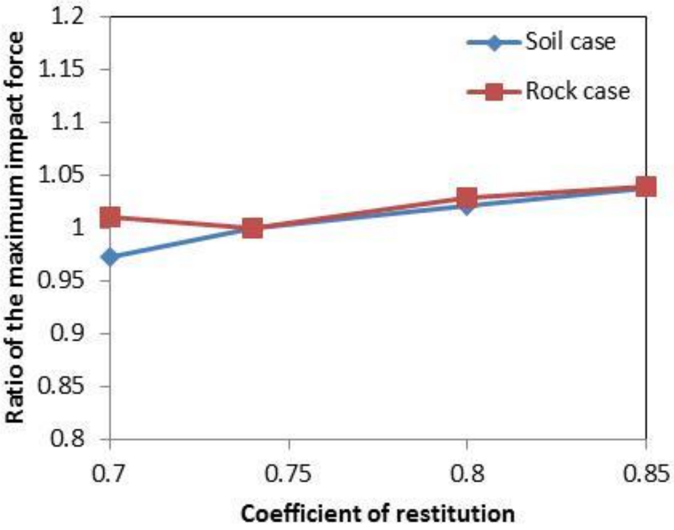

Fig. 9 The maximum impact force with coefficient of restitution

3.5 Flow damping

Figure 10 shows the maximum impact force along with a damping ratio of a fuel assembly. A flow damping ratio of a fuel assembly is considered because a flow damping ratio is used after considering an end-of-life condition effect. Due to a 5% increase of a flow damping ratio, the maximum impact force decreases with 13%. A flow damping ratio is one of dominant parameters. So, the flow damping test is important to determine the exact flow damping ratio.

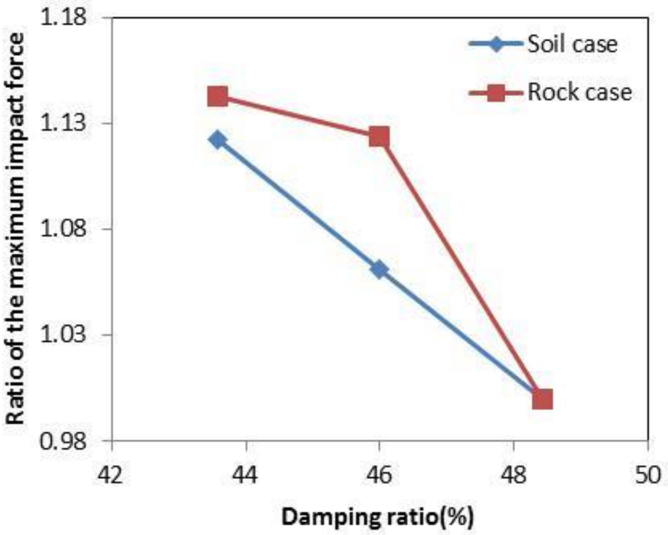

Fig. 10 Maximum impact force with a damping ratio of a fuel assembly.

3.6 Seismic load level

The maximum impact force is studied when a seismic load increases with 20%. Due to 20% increase of seismic load level, the maximum impact force increases with 39.1% and 41.16% for a soil case and a rock case, respectively. The nonlinearity due to the impact between fuel assemblies makes the higher impact force.

4. Discussion

To improve the safety margin of a fuel assembly for a seismic load, the grid crush strength should be improved and an impact force should be decreased.

Due to the grid spacer growth by an irradiation at an EOL condition, the decrease in a flexural rigidity of a fuel assembly may make the impact load to increase. External stresses applied to the spacer grids which are due to the interaction between the fuel rods' outer diameter and the spacer cells and springs could potentially contribute to the lateral growth.[3] The interaction between the fuel rods' outer diameter and the spacer cells and spring may be one of the parameter to improve the seismic safety margin of a fuel assembly. Under an EOL condition, the interaction between the fuel rods' outer diameter and the spacer cells and spring may be weakened by the grid spacer growth so it is important to study the characteristics of the skeleton fuel assembly which doesn't consider fuel rods.

The manufacturing method between a guide tube and a grid spacer which may increase the flexural rigidity of a fuel assembly should be considered to improve the seismic safety margin of a fuel assembly. The guide tube design may be also considered.

Design change to increase the grid crush strength of a fuel assembly may be considered to increase the seismic safety margin of a fuel assembly. Design change to increase the gird crush strength may make the increase of the through-grid stiffness. So, a design change to increase the grid strength is carefully applied.

5. Conclusion

The dominant characteristic parameters for the maximum impact force are a flexural rigidity, a through-grid stiffness and a damping ratio. When an improvement of grid crush strength is considered, a through-grid stiffness may increase. So, a method to improve the grid crush strength should be carefully considered. A rotation spring rate is not the dominant factor for the maximum impact force, but complexly affects the maximum impact force with a flexural rigidity. Coefficient of restitution is also not the dominant factor.

Due to an increase of a seismic load, the maximum impact force increases dramatically. The effect of an increase of grid stiffness on the maximum impact force is lower.

6. References

[1] UNITED STATES NUCLEAR REGULATORY COMMISSION, “IRRADIATION EFFECTS ON FUEL ASSEMBLYSPACER GRID CRUSH STRENGTH,” NRC INFORMATION NOTICE 2012-09, June 28, 2012(ML113470490).

[2] B. Matthews, B. Painter, H. Lebail, P.-H. Louf, V. Marx, “MECHANICAL ROBUSTNESS OF AREVA NP’S GAIA FUEL DESIGN UNDER SEISMIC AND LOCA EXCITATIONS,” 2017 Water Reactor Fuel Performance Meeting, Korea(2017).

[3] D. Schrire, J. Larsson, J. Loberg, “MODELLING PWR SPACER GRID GROWTH,” 2017 Water Reactor Fuel Performance Meeting, Korea(2017).