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Drop Impact Analysis for a Fuel Assembly Drop Event during Handling Procedure in Research Reactor

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ABSTRACT

In this research, the drop impact analysis of a fuel assembly in research reactor is carried out in preparation for the postulated erroneous handling accident of the fuel assembly. The fuel assembly drop accidents are classified based on where the accident occurs, i.e., at the inside of and outside of the reactor. Considering the two different drop situations, the finite element models are constructed and associated impact analysis procedures are made. For the accident outside the reactor, the most conservative assumption is that the fuel assembly directly impacts the pool bottom. The stress exerted in the fuel plate is obtained using implicit and explicit approaches, and compared with the stress limits. For the accident inside the reactor, the fuel assembly can impact the upper part of the standing fuel assembly bundles. The falling fuel assembly first hits the fixing bar, which is located at the top of each fuel assembly. The fixing bar plays a role of protecting the fuel plate from the external impact force. Thus, the fracture of the fixing bar caused by the impact force of the falling fuel assembly is investigated. Through the analysis, the suitability of each drop impact analysis procedure associated with the drop situations in the research reactor is assessed.

1. INTRODUCTION

In the research reactor, most of the burned fuel assembly is discharged, and all the other fuel assemblies are shuffled by moving them to other positions according to the fuel management strategy. During the loading and unloading procedures, the fuel assemblies are manipulated one by one using a handling system, and they are strictly limited to not go beyond the pool to preclude the possibility of excessive radiation dose for workers. Although the fuel handling tool is equipped with a double locking device to protect from disengaging the fuel assembly, a fuel assembly is assumed to be dropped accidentally during handling, as is classified by a postulated accident.

As a consequence of an impact by a dropping fuel assembly, the fuel plates of either the dropped fuel assembly or impacted fuel assemblies by external impact force can be damaged, which may cause a release of radioactive material from the fuel plates to the coolant. Thus, it is necessary to investigate the impact behavior of the fuel assembly so that the number of failed fuel plates shall not exceed the figures for the calculation of fission gas release in the dose analysis in the reactor building.

The purpose of the analysis is to check whether a failure of fuel plates has occurred considering the drop situations to be expected to occur in research reactor, and how the impact force has an influence on the fuel plates. In this study, the drop accidents are examined by classifying them into two major drop situations as our previous study, Yim et al. (2012). The impact analysis procedure suitable for each situation is constructed. The fuel assembly drop impact analysis is basically carried out using the explicit analysis code of LS-DYNA (2011). However, an implicit analysis using ANSYS (2011) is also utilized if possible, and the results are compared to those of an explicit analysis.

2. ANALYSIS MODEL

KAERI (Korea Atomic Energy Research Institute) designed a box-type fuel assembly used in research reactor. A plate type fuel, which has almost been standardized, is used in many research reactors. Fig. 1 shows the fuel assembly configuration. The fuel assembly contains 21 fuel plates. Each fuel plate is composed of a fuel meat with the surrounding cladding. At the top of the fuel assembly, the two cylindrical rod-shaped fixing bars are located to fix the upper part of the two side plates to maintain the spacing between the two side plates.

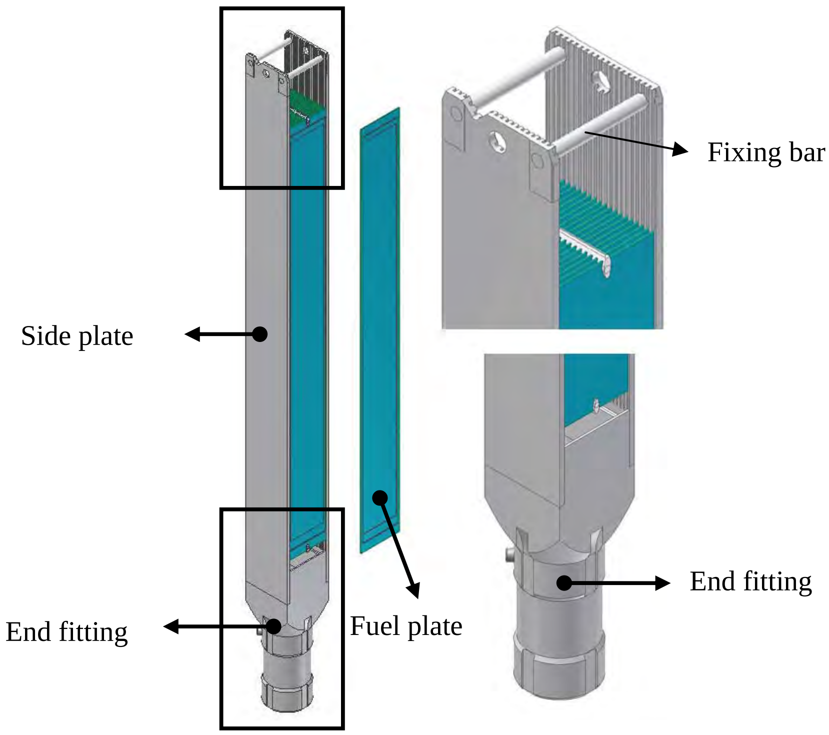


Fig. 1 Configuration of fuel assembly

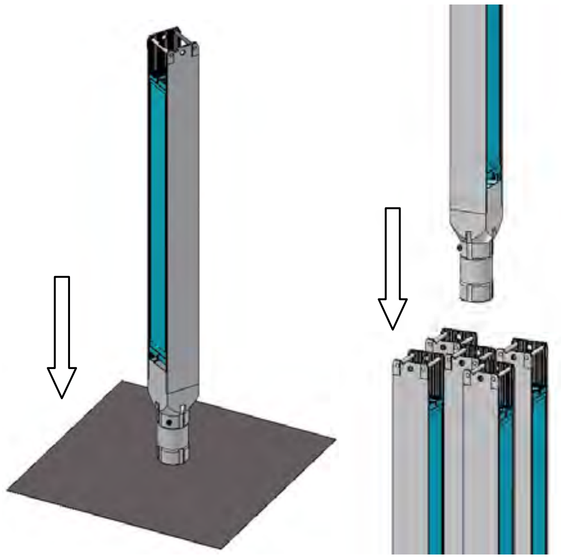
3 CLASSIFICATION OF DROP ACCIDENT

In the point of drop impact behavior on the fuel assembly, drop accidents can be basically classified into two cases based on where the drop accident occurs, outside or inside the reactor.

For the former case, the fuel assembly may drop onto the pool bottom or other mechanical components lying on the service pool. When the fuel assembly drops onto the pool bottom, the attainable drop height becomes the maximum value. By taking into account the fact that the pool bottom has almost a rigid property, and the maximum impact velocity is achieved at the moment of impact on the pool bottom, direct impact to the pool bottom, as shown in Fig. 2(a), is considered as the most conservative impact case. Two different analysis approaches, implicit and explicit, are used and their results compared.

For the latter case, the fuel assembly may drop onto the loaded fuel assembly bundles, as shown in Fig 2(b). In such case, the bottom part of the falling fuel assembly, end fitting, can hit the fixing bar first located on the top of the fuel assembly. Then, it subsequently damages the fuel plates of the standing fuel assembly if the fixing bar is fractured. If the fixing bar is not fractured, it can be concluded that the fuel plates will not fail because the fixing bar protects the fuel plates from direct impact of the falling fuel assembly. Therefore, it is important to check whether the fracture of the fixing bar caused from the impact force has occurred.

The pool depth in which the fuel assemblies are operated is assumed to be 10m. In the KAERI designed pool, the maximum drop height becomes 5.085m outside the reactor, and 3.160m inside the reactor. The analytical calculation considering the drag force reveals that the terminal velocity of the fuel assembly is 5.36m/s. The highest attainable impact velocities on the fuel assembly for accidents outside and inside the reactor become 4.58m/s and 4.0m/s, respectively.



(a) (b)

Fig. 2 Drop accident cases: (a) fuel assembly drop on the pool bottom; (b) fuel assembly drop on loaded FA bundles

4. FINITE ELEMENT ANALYSIS OF FUEL ASSEMBLY DROP ACCIDENT

The drop accidents can be classified into two situations. In this study, a separate finite element modeling and analysis strategy are constructed for each case.

For a drop accident outside the reactor, the dropped fuel assembly may directly drop on the pool bottom or impact the other component such as fuel storage rack. When the fuel assembly is dropped, the fuel assembly is impacted and physically damaged. Since the most of shock wave may be absorbed by the bottom part of the fuel assembly, end fitting, the fuel plates may be only slightly bent or mechanical damaged. A quantitative assessment on how much the fuel plate is damaged is required for an assessment of the fission product release. In this regard, the stress of the fuel plate is calculated, and is compared with the design criteria of the ASME code (2004). Since it is expected that the failure behavior of the fuel assembly is not too much, two different analysis approaches, implicit and explicit, are carried out, and their results such as stress and contact force are compared.

For an accident inside the reactor, a dropping fuel assembly may hit the standing fuel assembly bundles. Since the fixing bar plays a role of protecting fuel plates from external impact force, it is important to check whether the fracture of the fixing bar has occurred. It is impossible to implement the fracture mechanism in an implicit analysis. Thus, only an explicit approach is utilized for this problem. The complicated modeling, which does not have an influence on impact results, is simply modeled using a dummy model. The upper part of the standing fuel assembly is also simply modeled, which will be shown in the next session.

4.1 FUEL ASSEMBLY DROP ACCIDENT AT OUTSIDE OF THE REACTOR

The fuel assembly at the moment of impact is modeled using a finite element. The fuel assembly and pool bottom are modeled so that they are sufficiently close to each other. The pool bottom is coarsely modeled with high stiffness. Then, an initial impact velocity of 4.58m/s is imposed on the fuel assembly as the initial condition. Contact surfaces should have been designated by contact elements before the analysis. The surface-to-surface elements, Conta173 of ANSYS, are used. In the analysis, the geometric nonlinear effect is considered. For explicit dynamics such as LS-DYNA, there is no specific contact element. As a simple indication of contact surfaces, the type of contact between them is necessary.

Fig. 3 shows the stress intensity history of the fuel assembly resulted from ANSYS. As the impact starts, the stress is concentrated at the bottom tip at the moment of impact, and then, propagates throughout the body and diffuses away over time.

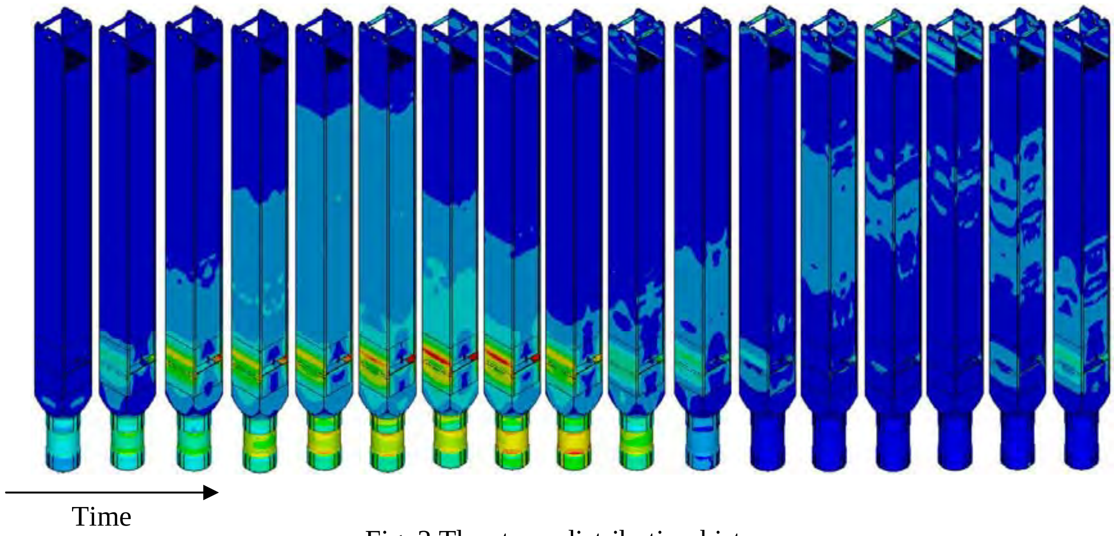


Fig. 3 The stress distribution history

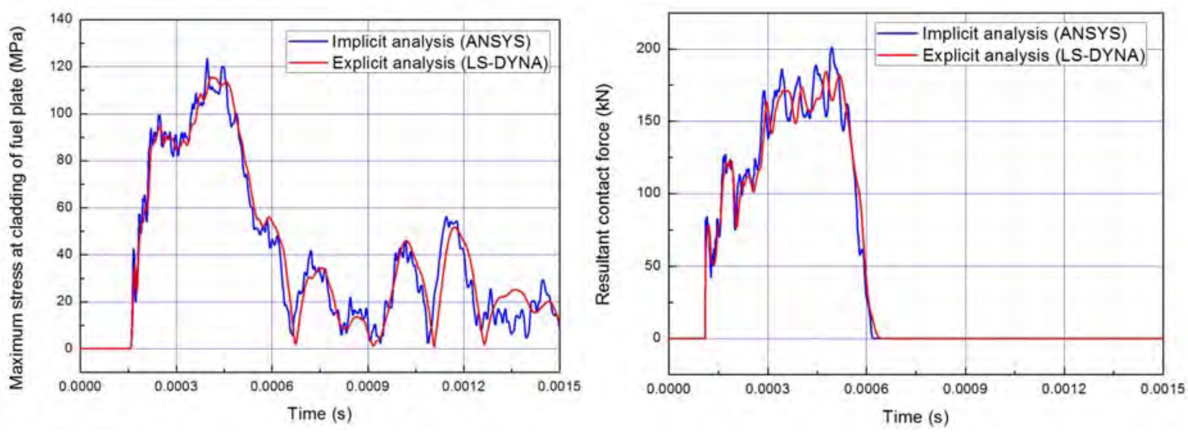


Fig. 4 The maximum stress history at cladding of fuel plate and contact force history

The left figure in Fig. 4 is the maximum stress history of the cladding of the fuel plate, and the right figure shows the contact force over time. The maximum stress at the fuel plate is around 120MPa, which is lower than the design limit for the accident case. Thus, it is expected that the fuel plate structural integrity is ensured. Comparisons between explicit and implicit methods are also made in the figures. The graphs show that the patterns of stress distribution and contact force are similar for most regions. The explicit analysis results follow well with those of the implicit analysis. Although there is a little delay on the profiles between the two methods, this slight discrepancy is acceptable. It is observed that the values by the implicit methods oscillate more than those by the explicit analysis.

In summary, even though the drop accident occurs outside the reactor at a certain attainable maximum drop height, the structural integrity of fuel plate is predicted to be maintained.

4.2 FUEL ASSEMBLY DROP ACCIDENT INSIDE THE REACTOR

During the fuel assembly loading and discharging procedures in the reactor, the fuel assembly may inadvertently drop on the fuel assembly bundles standing in the grid plate. In such case, the dropping fuel assembly hits the fixing bar first, as shown in Fig. 5. The fixing bar, which is located in the upper part of the fuel assembly, plays a role of a first barrier for protecting the fuel plates from the external direct impact force. Most of the kinetic energy will be observed by the fixing bar. If the fracture of the fixing bar is occurred, an additional impact analysis on the fuel plate after the fixing bar fracture is necessary. If not, the subsequent impact on the fuel plates will be precluded, which means the fuel plate integrity is ensured.

Fig. 5 is a finite element model at the moment of impact. Since the upper part of the falling fuel assembly has nothing to do with the contact region, it is modeled using simple dummy model, which has the same weight. The two fixing bars are bonded to the side plates by welding. To implement the welds into the finite element model, the additional contact condition between the fixing bar and side plate is imposed in addition to that between the falling end fitting and fixing bar. The dropping fuel assembly is modeled to be located just above the fixing bar of the standing fuel assembly. The falling end fitting is positioned so that the longitudinal axis of the end fitting impacts to the fixing bar. The impact velocity is imposed on the falling fuel assembly as the initial condition.

Fig. 6 shows the stress distribution history. As shown in the figure, the fracture of the fixing bar has not occurred. The stress is concentrated on both of the fixing bar end parts.

5. CONCLUSION

In this study, the overall analysis strategy of the fuel assembly drop event in a research reactor is presented. The drop accidents are classified into two accident cases based on where the accident occurs, and a numerical simulation of each accident is carried out using the finite element analysis.

As an accident outside the reactor, the direct drop of the fuel assembly on the pool bottom is considered a conservative case. The fuel assembly and pool bottom are modeled into finite elements. Two different analysis schemes, implicit and explicit, are used and their results are compared. For the design criteria, the ASME code is adopted. The maximum stress of the fuel cladding is lower than the design limits, which leads to the fuel integrity being maintained, and the fission gas release being precluded.

As an accident inside the reactor, we focused on the fracture of the fixing bar at the top of the standing fuel assembly because the fixing bar plays the role of first barrier from the impact force of falling fuel assembly. It was observed that no failure of the fixing bar occurs, which means the falling fuel assembly cannot impact the fuel plates on the standing fuel assembly bundles.

Through the analysis, the suitability of each drop impact analysis procedure associated with the drop situations in the research reactor is shown.

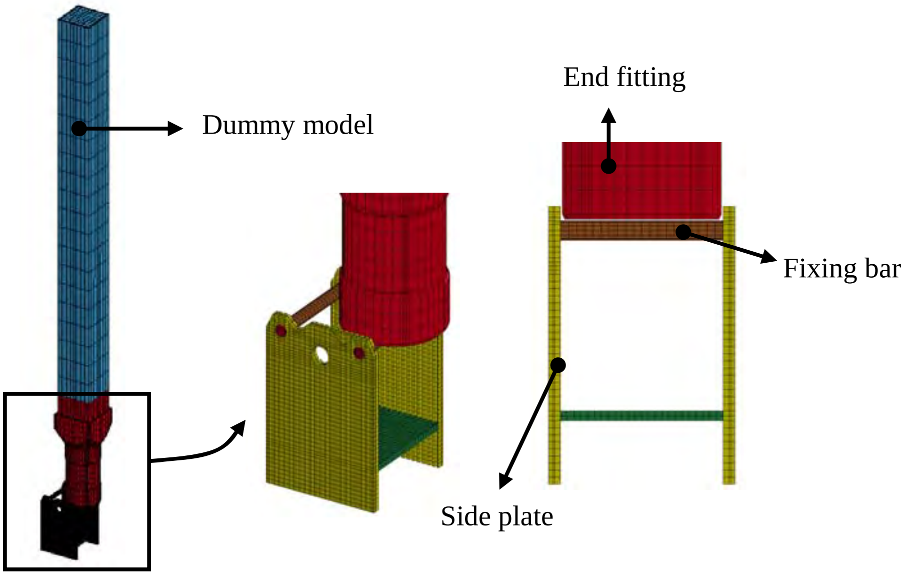


Fig. 5 Finite element models at the moment of impact

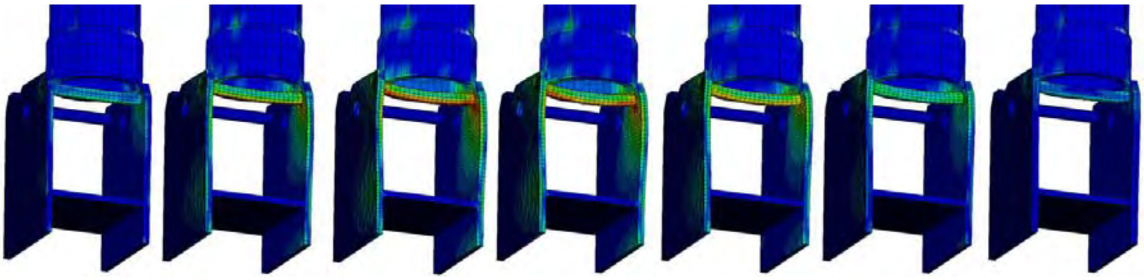


Fig. 6 The stress distribution history

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