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Development of Dynamic Impact Analysis Model in KALIMER Fuel

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Abstract

A dynamic impact analysis model has been developed to analyze structural behaviors of KALIMER fuel pins under impact load. This study has been carried out to assess the mechanical integrity of fuel pin design. Fuel pins are modeled by 3-D finite element method with shell and beam model with contact spring. To construct an appropriate fuel pin model, the dynamic analyses are performed during several impact load conditions.

1. Introduction

KALIMER fuel is related to a fuel handling system which provides the services for handling all core assemblies. The fuel handling systems and components should also be satisfied with the requirement by means of maintenance, replacement, or redundancy. The safety related systems for the fuel handling system are designed to be operable during an operating basis under earthquake conditions. The seismic response spectrum to be used for seismic load analysis is considered for fuel dynamic analysis. In the design and analysis of a fast breeder reactor fuel duct assemly, there are a number of problems related to irradiation effects during long-term operation. It is described that the utilization of high-burnup capability of FBR fuels is important to develop the fuel by reducing the fuel cycle cost. However, when fuel burnup is increased, neutron fluence and pin inner pressure are also increased, and then dilation and bowing of fule pin bundle could be so large as to mechanically interact with duct wall. The original fuel pins in assembly before irradiation are changed into the deformed shape after high irradiation[1-3]. Fuel pins in assembly are dispersed by interactions with the duct inner walls. The fuels meet the design capability, not only in neutronics performances but also in structural integrity. However the fuel handling design basis is considered to preclude dropping fuel elements. The probability to drop the fuels onto the building floor still remains. Therefore, model development of structural analysis code is necessary to predict fuel dynamic performances.

2. Dynamic Analysis Model

The transient dynamic analyses are used to solve the response of a structure to a time-history forcing function. In its most general form, this analysis type allows for any nonlinearities. The governing equilibrium equation is

$$[M]\ \ddot{u} + [C]\ \dot{u} + [K]\ u = F(t) \tag{1}$$

where,

$[M]$ = structure mass matrix,
$[C]$ = structure damping matrix,
$[K]$ = structure stiffness matrix,
$\{F(t)\}$ = time-dependent forcing function,
u = nodal displacement vector,
$\dot{u}$ = nodal velocity vector,
$\ddot{u}$ = nodal acceleration vector.

For a finite element system, the structure stiffness matrix is given by

$$[K] = \sum_{i=1}^{NE} [K_i^e] \tag{2}$$

where, NE = number of elements,

$[K_i^e]$=individual element stiffness matrix.

The dynamic analysis of a fuel rod are used to solve the response of a structure to a time-history forcing function. One is a dynamic mode to drop fuel on to floor. There is another dynamic mode to contact pad behavior: the choice of a dynamic stiffness value is of major importance in order to perform mechanical core computations under a seismic excition.

2. Fuel pin model

The straight pin of an array before irradiation is considered into the contact form within duct wall. As mentioned, the basic concept of the dynamic load phenomenon is shown in Figure 1. One fuel pin is modeled by a combination of three-dimensional model structured by the finite element method. A fuel pin is divided into a combination of basic elements as shown in Figure 1. In sample calculation, a single fuel pin model for three-dimensional elements is adopted and connected to the adjacent pins and duct walls. The basic element is composed of a one shell element which expresses fuel pin clad stiffness, and four spring elements which express fuel pin with impact load. Two-pin model for three-dimensional elements is also adopted and connected to the adjacent pins and duct wall in Figure 2. The element model is composed of a one shell element which express fuel pin clad stiffness, and six spring elements which expresses two fuel pins with impact load. Impact load is assumed to impulse the fuel pin within 0.2 msec each time.

3. Analysis and Results

The dynamic impact model for KALIMER fuel has been developed to conform with the structural integrity of fuel design. A series of calculations were performed to analyze a single fuel pin model with a combination of shell and beam elements. The ANSYS code[4] was applied to a typical fuel pin model to perform its structural analysis under dynamic impact load conditions.

Figure 3 shows the stress contour of a single pin model caused by impact load at time t=0.04 s. The condition is given at the impact load Px=500 kg. The maximum value of stress intensity is represented at the contacted upper node with adjacent pins and duct wall. The pin model is slightly deformed near to contacted nodes.

Figure 4 shows the stress contour of two-pin model caused by impact load at time t=0.008 s. The condition is given at the impact load Px=500 kg.

The displacement profile of fuel pin at two-pin model during impact load time is shown in figure 5. Figure 6 shows the velocity profile during the impact load time. The displacement and velocity profile is reduced as vibrational mode shape since load time is gone. A comparison of the stress intensity of single pin between two-pin model is shown in Figure 7. It is observed that increasing values of stress intensity lead to increasing values of impact load. And the stress intensity profile for single pin model is slightly higher than those of two-pin model versus impact load. This predicts that the stress intensity of single pin model could be proved to represent more conservative result than two-pin model.

4. Conclusion

A single pin and two-pin model in KALIMER fuel assembly have been developed to analyze fuel assembly under dynamic impact load behaviours. A single pin and two-pin model approach are not enough to predict the dynamic phenomenon for fuel assembly. It is considered to be a possible method. The present models are to enhance the accuracy for predicting the real fuel model, and a new method will be continually developed by further study.

References

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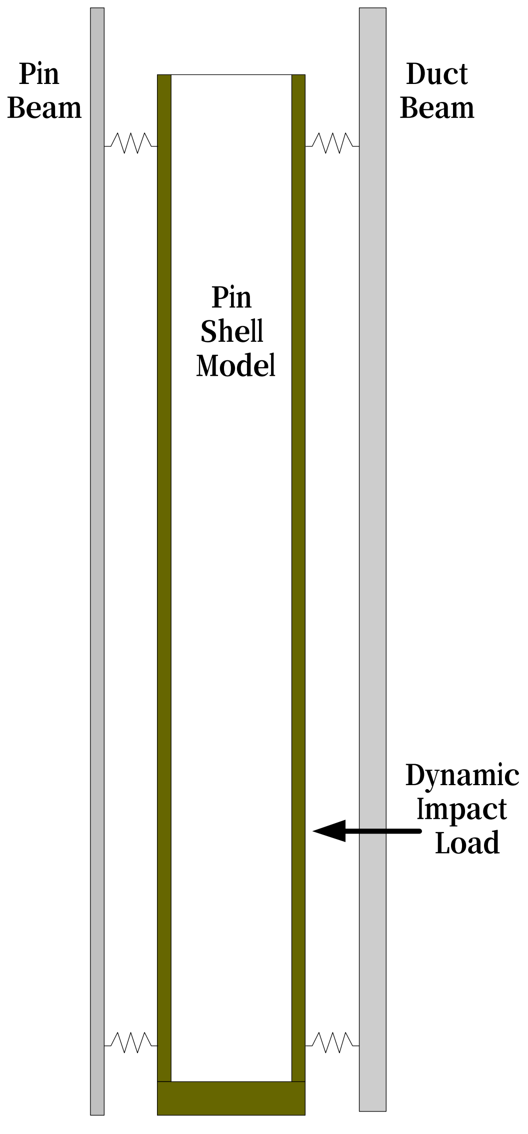

Figure 1 Single pin model for dynamic load

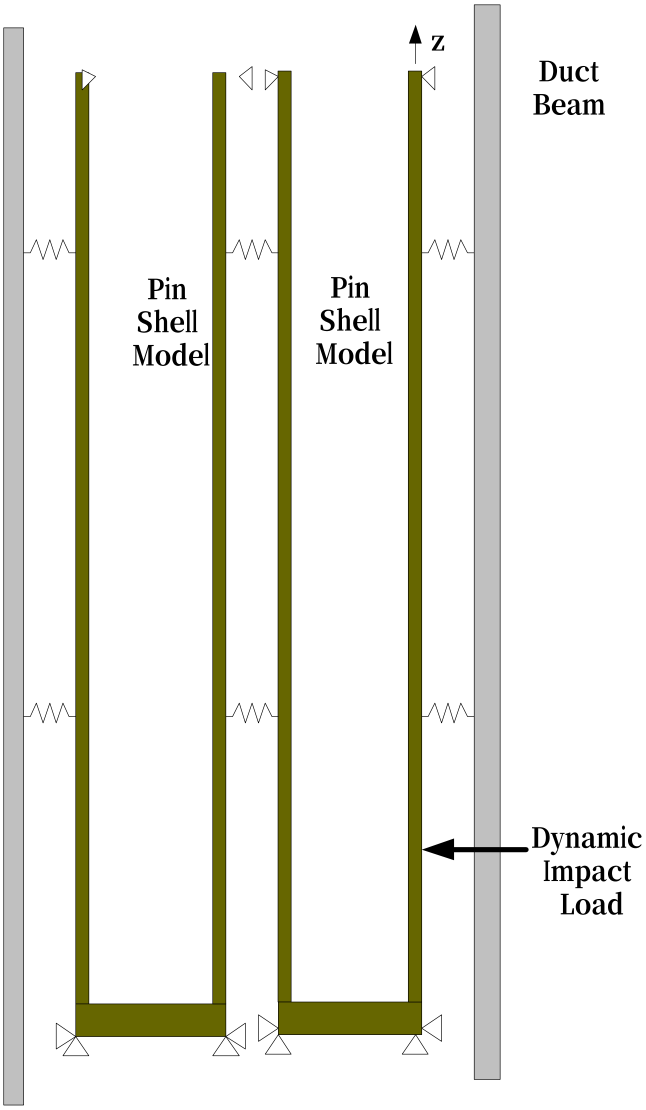

Figure 2 Two-pin model for impact load

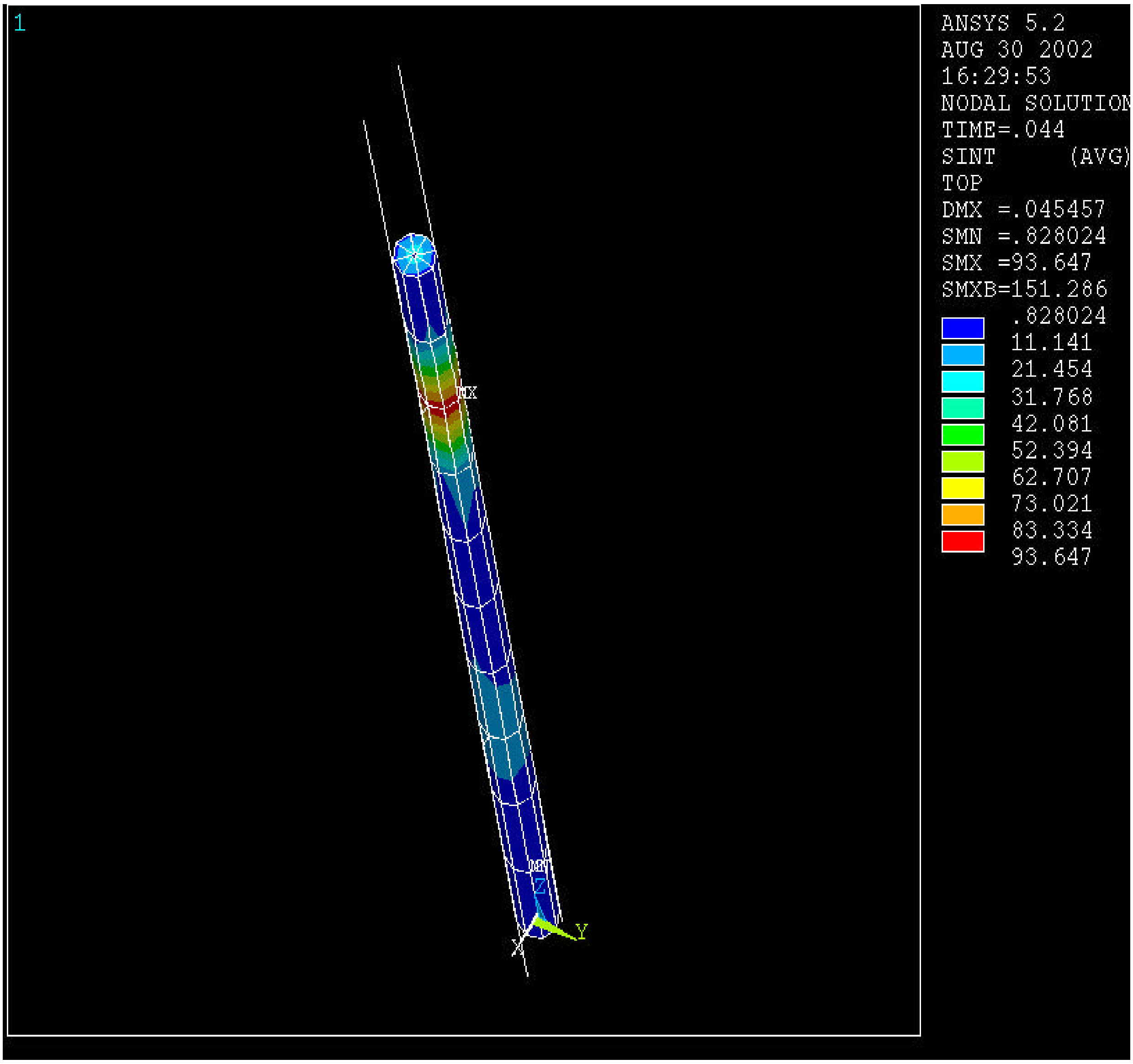

Figure 3 Stress contour of single pin model under 500 kg impact load at t=0.44 s

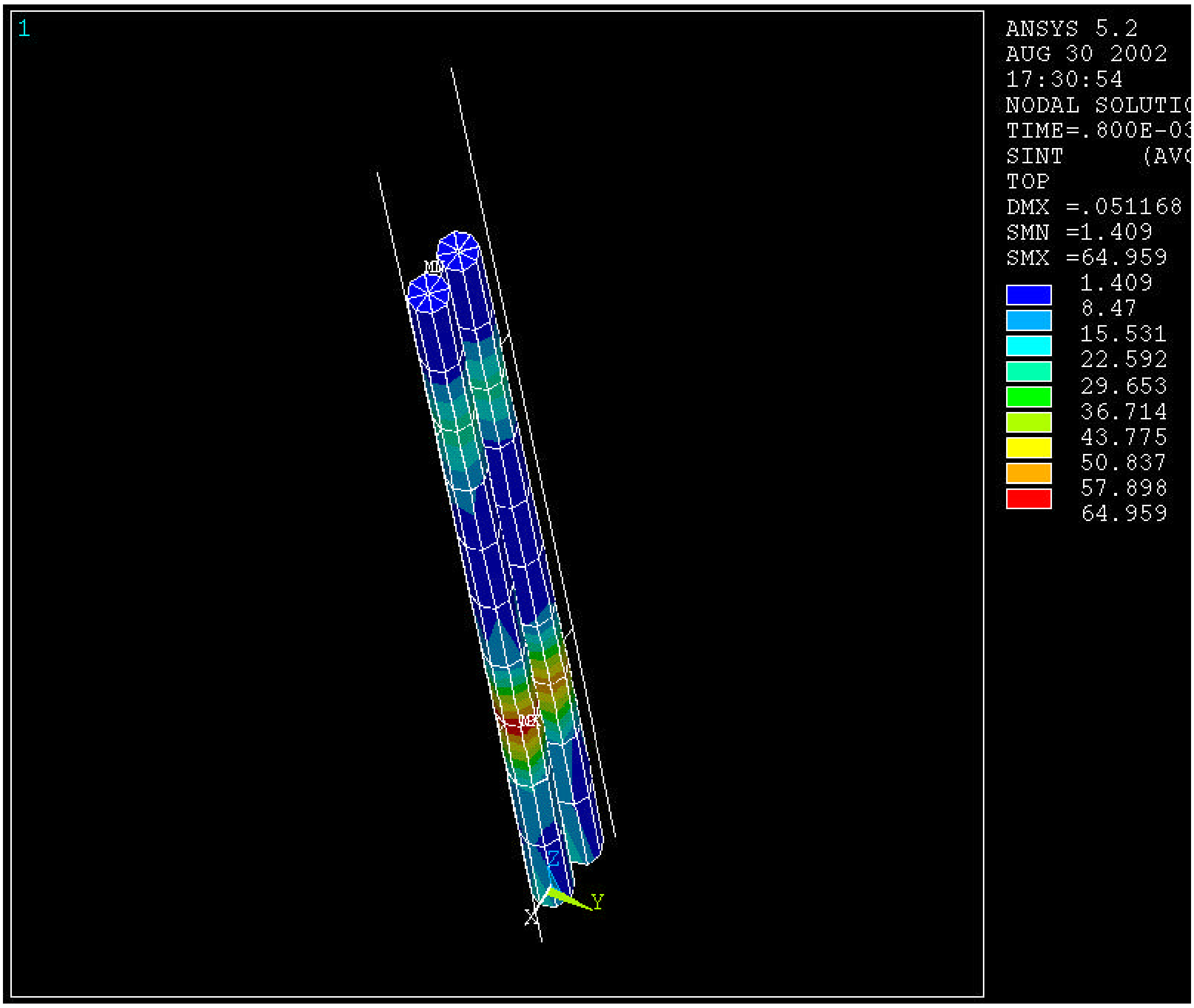

Figure 4 Stress contour of two-pin model under 500 kg impact load at t=0.008 s

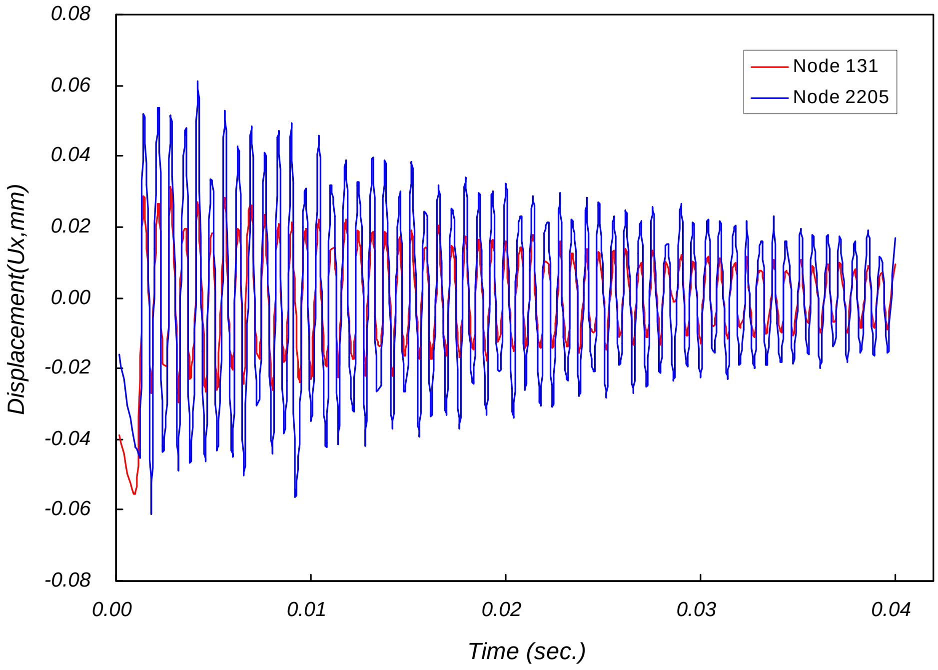

Figure 5 Displacement profile of fuel rod versus load time at two-pin model

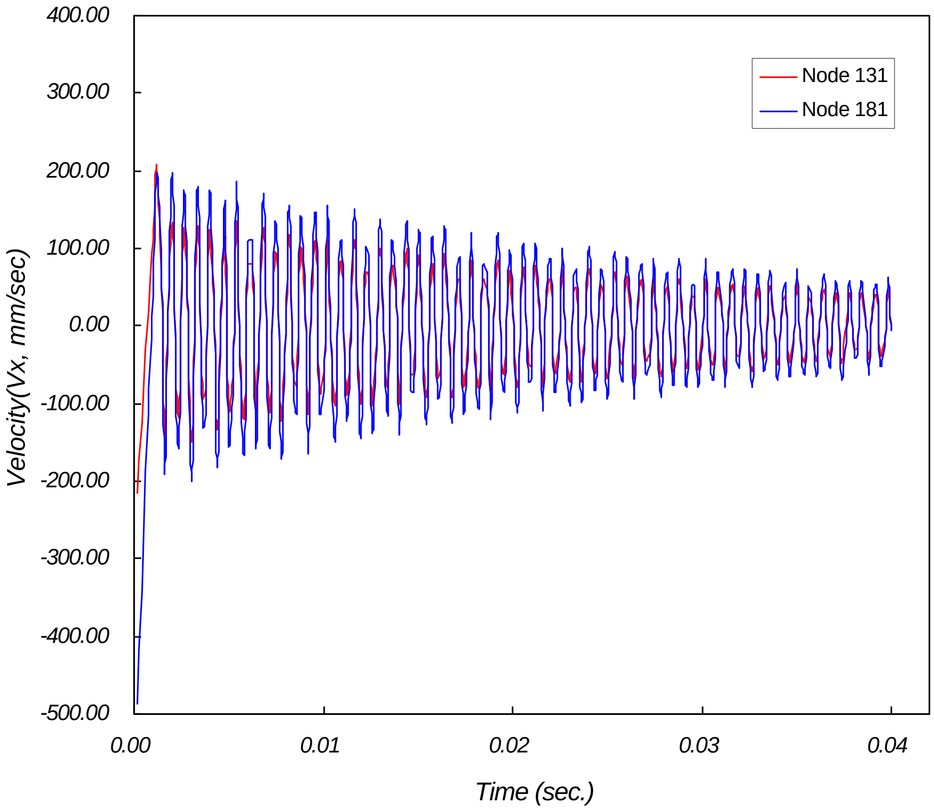

Figure 6 Velocity(Vx) profile of fuel rod versus load time

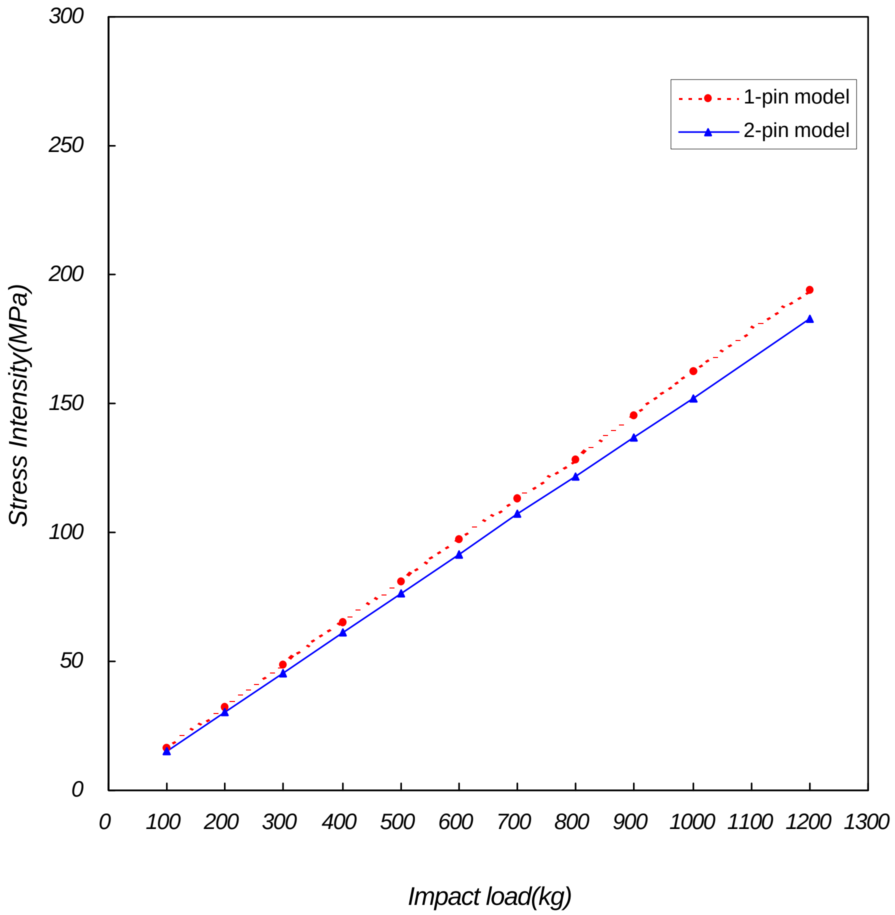

Figure 7 Stress intensity(MPa) profile of fuel rod versus dynamic impact load (single-pin model, two-pin model)