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Impact Analysis Modeling Development for CANFLEX Fuel Bundle

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Abstract

The nonlinear dynamic analyses were performed by newly developing an appropriate impact modelling for the evaluation of the CANFLEX fuel bundle structural integrity during the refuelling period. The initial load under the refuelling condition is considered as initial velocity at impact incident, and the impact of one bundle contacted another bundle for at short time is studied by performing several dynamic analysis method. The impact analysis shows to predict an appropriate velocity and acceleration profile according to load time history for two bundles impact.

1. Introduction

The CANDU-6 calandria contains 380 horizontal fuel channels. The heavy water coolant passes through the fuel bundle string contained in the pressure tube. During the normal operation, the fuel bundles are randomly loaded into the fuel channel under the on-power reactor condition. The CANFLEX fuel bundle has been developed by KAERI and AECL jointly to facilitate the use of various fuel cycles in CANDU-6 reactor[1-6]. The static and dynamic structural analysis on CANFLEX fuel bundles in the fuel channel during the refuelling period would be an interesting subjects.

The present structural analysis is considered in dynamic impact load due to the bundle movement by coolant flow during the refueling. The bundle is moved mainly by hydraulic drag force which is generated by the flow blockage in the cross section of fuel bundle components in channel. The pressure drop data measured in the test can be applicable to predict the drag force. During a normal refuelling sequence, the first bundle loaded is accelerated a short distance by the coolant flow as it passes through the upstream liner region and contacted the fuel bundles already existed in the channel. The impact load increases with bundle velocity which depends on the acceleration distance and the coolant flow in the channel.

This nonlinear dynamic analyses with the ANSYS code[7] were performed to develope an appropriate impact modelling for the evaluation of the structural integrity at the bundle impact during the refueling period. The developed analysis modelling is applied by evaluating an appropriate CANFLEX fuel bundle design.

2. Dynamic Load and Solution Method

The hydraulic drag load is mainly due to the pressure drop through the fuel bundle string in channel. Fig. 1 shows an overview of the fuel bundles impacted to one bundle in a fuel channel during the refuelling. This load affects on terminal velocity at moving bundle during the refueling service. The terminal velocity V_t is achieved when the hydraulic drag (F_H) across the moving bundle is equal to the dynamic friction force, (F_D)

$$F_H \approx \rho(V_c - V_t)^2 \qquad (1)$$

where, V_c is the coolant velocity in empty channel.

The transient dynamic equilibrium equation of interest is as follows for a linear structure,

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F^a\} \qquad (2)$$

where, $[M],[C],[K]$ = *structural mass, damping, stiffness matrix*
$\{\ddot{u}\},\{\dot{u}\},\{F^a\}$ = *nodal acceleration, velocity* and *applied load vector*

The procedure employed for the solution of the linear equation(2) is the Newmark time integration method. The Newmark method uses finite difference expansions in the time interval Δt, in which it is assumed as follows ;

$$\{\dot{u}_{n+1}\} = \{\dot{u}_n\} + [(1-\delta)\{\ddot{u}_n\} + \delta\{\ddot{u}_{n+1}\}]\Delta t \qquad (3)$$

$$\{u_{n+1}\} = \{u_n\} + \{\dot{u}_n\}\Delta t + \left[\left(\frac{1}{2} - \alpha\right)\{\ddot{u}_n\} + \alpha\{\ddot{u}_{n+1}\}\right]\Delta t^2 \qquad (4)$$

where, α, δ = Newmark integration parameters, $\Delta t = t_{n+1} - t_n$

$\{u_n\}$, $\{u_{n+1}\}$ = nodal displacement vector at time t_n, t_{n+1}

Since the primary aim is the computaion of displacements $\{u_{n+1}\}$, the governing equation (2) is evaluated at time t_{n+1} as:

$$[M]\{\ddot{u}_{n+1}\} + [C]\{\dot{u}_{n+1}\} + [K]\{u_{n+1}\} = \{F^a\} \qquad (5)$$

3. Dynamic Structural Analysis

3.1 Analysis Modeling

(1) Small Fuel Bundle Model (8-rods fuel bundle)

The dynamic analysis model is considered in dynamic impact load due to the bundle movement by coolant flow during the refueling. The bundle is moved mainly by hydraulic drag force which is generated by the flow blockage in the cross section of bundle components. During a normal refuelling sequence, the first bundle loaded is accelerated a short distance by the coolant flow as it passes through the upstream liner region and contacted the fuel bundles already existed in the channel.

The finite element model of small fuel bundle is a beam model which are composed of 8 fuel elements connected with endplate webs. Endplates and fuel rods are modelled as beam elements, using different material properties. The endplates of two small bundles are modelled with 3-D elastic beam element. Fuel bundle elements are modelled as 3-D elastic beams with rod element properties included in sheath and meat. The length of each rod is divided into six segments.

The bundle #2 is moved to bundle #1 by coolant flow and impact to bundle #1 with velocity at short time. The adjacent endplates between bundle #1 and #2 are modelled with contact element defined by 3-D point-to-point. Contact element represents two surfaces which may maintain or break physical contact. The interface between a target bottom and endplate at the downstream of bundle #1 is connected as another contact element defined by 3-D point-to-surface. The target bottom is constrained to all degrees of freedom. The centre node on each of the two endplates of all fuel bundles have their transverse displacements(Ux, Uy) restrained to fix these nodes in spacers. Fig. 2 shows an overview of small bundles model located in 3-D geometry(x,y,z) in a fuel channel.

(2) Fuel Bundle Model (43-rods fuel bundle)

The finite element model for two bundles is a beam model which are composed of CANFLEX 43 fuel rods connected with endplate webs. And the spacer pads at the center of bundle are modelled as rigid truss elements with 3 translational degrees of freedom. Fig. 3 shows an overview of CANFLEX fuel bundles beam model located in 3-D geometry(x,y,z) in a fuel channel.

3.2 Dynamic Analysis

The dynamic analyses were performed to develop an appropriate modelling for bundle impact by using the various modelling elements and constraint conditions. To verify the modelling simulation of CANFLEX bundles, the small bundle model I for impact structure analysis consists of 188 nodes and 256 elements. The dynamic analysis was mainly carried out to develop an impact modeling by using small bundle.

A transient analysis involves loads as a funtion of time. The first step in applying transient loads is to establish initial conditions. A load condition for impact requires by applying appropriate initial velocity over a time step. The velocity is established by applying small displacements over a small time interval on the part of the fuel bundle movement. Prior to dynamic analysis, the static analysis was calculated first so as to give an initial velocity on the moving bundle # 2 at load step 1. At load step 2, the transient time integration is turn on by starting the solution and solve until the time at the end of the load step. The present analyses for developing the impact model were performed to review the acceleration, velocity profile, displacements and deformed shapes through the transient load time history during the impact behavior.

4. Results and Discussions

The nonlinear dynamic analyses were performed to develope an appropriate impact modelling for the evaluation of the structural integrity due to the bundle impact during the refueling period. Fig.4 and 5 shows the velocity distribution versus load time history for the impact. The velocity profile of bundle #1 contacted with target bottom is shown in Fig. 4. Fig. 5 is shown the velocity profile at bundle #2 which give an impact on bundle #1. The velocity of bundle #2 until t=0.002 sec is given to be constant with -5,000 mm/s(v=5 m/sec.). One initial load condition is the velocity of 5,000 mm/sec. After impact time t=0.002 sec, the velocity increases up rapidly to show the rebound phenomenon and then maintain a constant velocity with reverse direction. In Fig. 6 and Fig. 7, the acceleration profile is shown as g-value which is represented in impact energy. As shown in Fig. 6, the bundle impact occurs at very short time period of 0.0005 sec. The maximum value is given to be approximately 6,500 g-value and this is due to higher stiffness of bundle endplate. Fig. 8 shows the slightly deformed shape of two bundles which is moved to reverse axial direction at the end of impact time period.

5. Conclusion

The dynamic analyses for CANFLEX fuel bundles in the fuel channel were carried out to develope an new impact modeling for the evaluation of the structural integrity during the refuelling sequence by various nonlinear dynamic methods. It is concluded as follows:

(1) A small bundle modeling was newly developed to predict on the impact behavior of two bundles during the refueling.

(2) The nonlinear impact analysis shows that an appropriate velocity and acceleration profile according to load time history were obtained for short time period.

(3) The small bundle modeling is enough to evaluate an impact behavior of the CANFLEX bundles. And so the CANFLEX fuel bundle impact analysis will be continously studied in detail to improve and optimize the fuel design.

6. References

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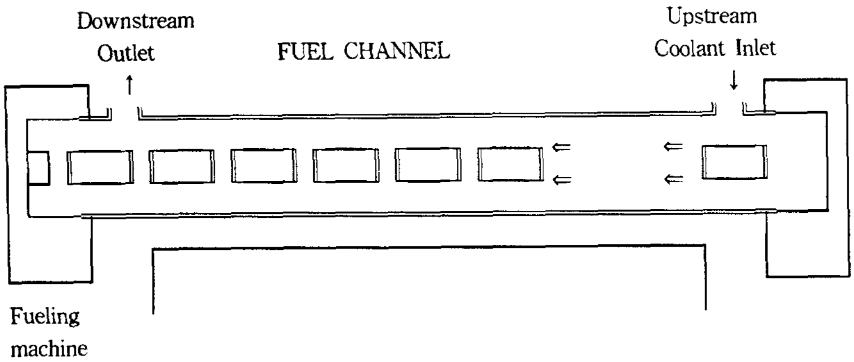


Fig. 1 Impact Load Configuration in a Fuel Channel during Refueling

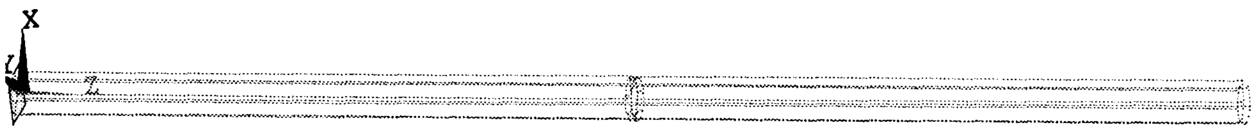


Fig. 2 Small Bundle Geometry Model for Impact Analysis Modeling

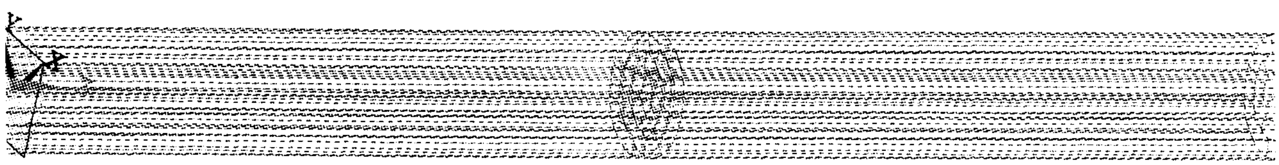


Fig. 3 CANFLEX Fuel Bundle Model for Impact Analysis

g. 4 Velocity Profile versus Time History for Bundle #1

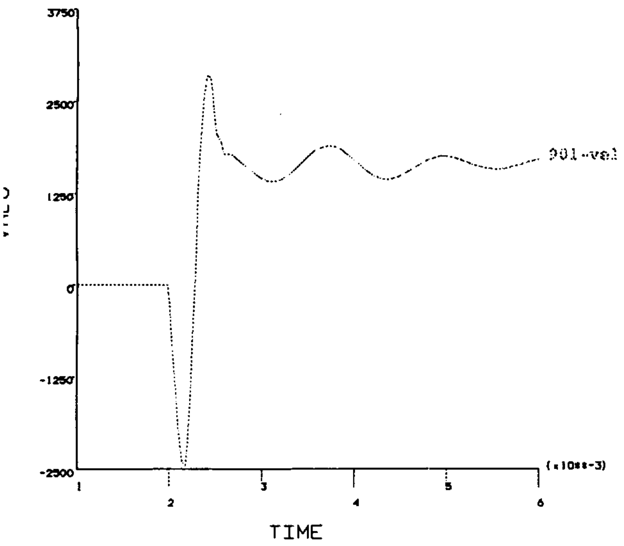
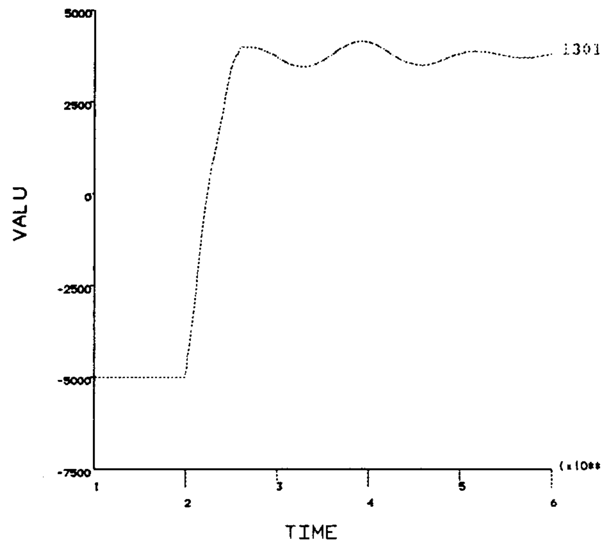


Fig. 5 Velocity Profile versus Time Histor for Bundle #2



g. 6 Acceler.(g) Profile versus Time History for Bundle #1

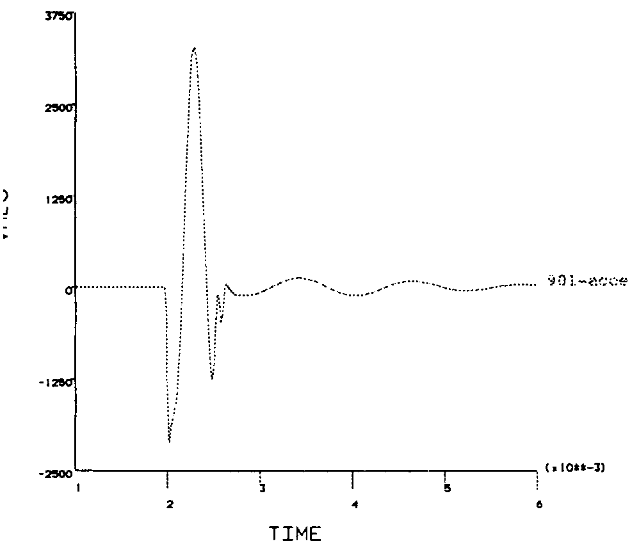
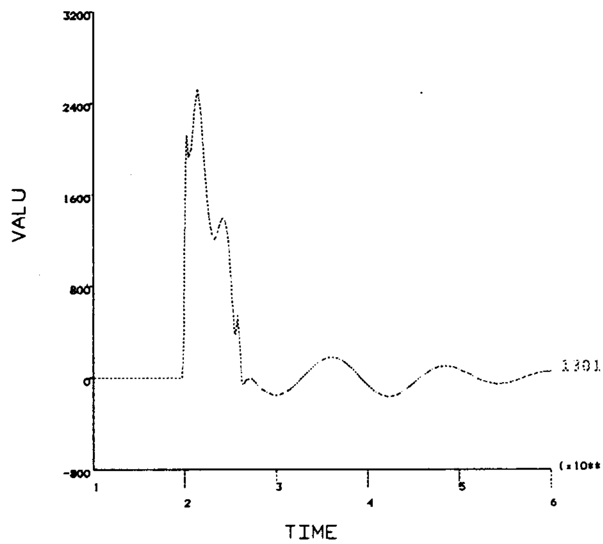


Fig. 7 Acceler.(g) Profile versus Time Histo for Bundle #2



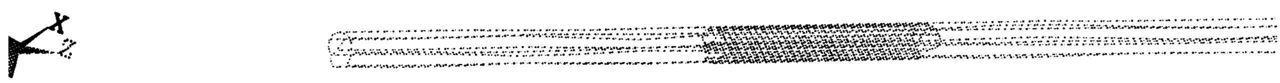


Fig. 8 Deformed Shape of Bundle #1 and #2 after Impact