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COMPUTATION OF HYDRAULIC FORCES ON A BWR VESSEL AT FEEDWATER PIPE BREAK USING RELAP 5 CODE

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Abstract. Pipe breaks are a major consideration when designing electrical power generation plants, especially for nuclear power plants. The most important pipes in nuclear power plants are those which are connected to the reactor vessel. The reactor vessel, its internal parts, and the connected pipes themselves all have to withstand forces generated due to pipe break. In this paper we give some results of the calculated forces on a BWR vessel at feedwater pipe break. The thermohydraulic calculations have been done by using the RELAP 5 code. This code has proven to be appropriate for calculation of hydraulic forces in such a situation.

Keywords: Hydraulic loads, break flow, RELAP 5

1. Introduction

The assumption of a pipe break is a general design basis of electrical power generation plants, especially of nuclear power plants. Forces generated due to pipe break must be withstood by the reactor vessel including its internal parts and the pipes themselves. Pipes connected to the reactor vessel are the most important ones in nuclear power plants. Usually the most severe pipe breaks are the break of those large pipes that are connected to the water filled part of the reactor vessel. These large diameter pipes include the recirculation lines for reactors with external recirculation systems and the feedwater lines for reactors with internal recirculation systems. Figure 1 shows a principal sketch of a boiling water reactor (BWR) and the main pipes connected to the water filled part of the reactor vessel.

In this paper we give some results for forces calculated for a BWR vessel and its internal vessel (called the moderator vessel) at feedwater pipe break.

2. Simulation using RELAP 5 of a pipe break

The RELAP 5 code (Reactor Ex-cursion and Leak Analysis Program) [1] has been continuously developed since the 1970s. Idaho National Engineering Laboratory (INEL) was the first principal code developer contracted by the Nuclear Regulatory Commission (NRC). The latest code development is an international effort called CAMP [2] and the principal code developer is Information Systems Laboratories (ISL), a San Diego based employee-owned research and development company [3]. ISL acquired the code development contract from SCIENTECH Inc.

The RELAP5/MOD3 computer code uses the two-fluid model, consisting of steam and water, with the possibility of the vapor phase containing a noncondensable component and the liquid phase containing a nonvolatile solute. The two-fluid model means that the code solves the continuity equation, the momentum equation and the energy equations for both the fluid phase and the gas phase. An Eulerian boron-tracking model is used in RELAP 5 that simulates the transport of a dissolved component in the liquid phase. There is a field equation for the conservation of the boron solute. The numerical solution scheme uses results in a system representation using control volumes connected by junctions. A physical system consisting of flow paths, volumes, areas, etc., is simulated by constructing a network of control volumes connected by junctions. Such a representation of a BWR vessel can be seen in Figure 1b.

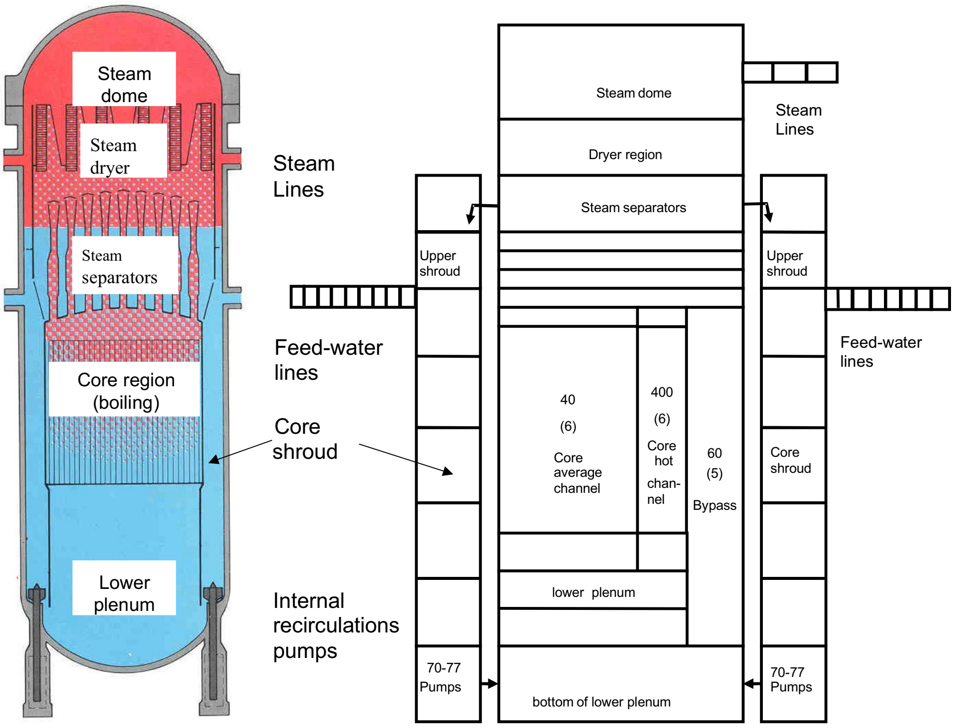

Figure 1. (a) Principle sketch of a BRW with internal recirculation system. (b) nodalization of a BRW vessel for simulations with the RELAP 5 code

The Swedish Nuclear Power Inspectorate for auditing calculations developed the model in Figure 1b. The main purpose for the model was to compute the maximum cladding temperature in the core hot channel with different assumptions on vessel break sizes. Basically this is the model that has been used in our computations. The model has been adapted with some updates to the force calculations.

3. Flow induced forces on pipes and structures

Many investigators [4, 5] have reported the theoretical solutions of unbalanced force on pipes and structures due to blowdown. The basic principles are summarized here. The resultant force acting on a container by the fluid it contains results from two sources (a) the pressure acting on the wetted surfaces of the container, and (b) the friction forces between the fluid and the container acting on the wetted surfaces of the container, i.e.

$$\mathbf{R} = \int\limits_{w.s.} p\mathbf{n}\mathrm{d}s + \int\limits_{w.s.} \boldsymbol{\tau}\mathrm{d}s \tag{3.1}$$

where

$\mathbf{R}$	resultant force acting upon container by fluid,
p	local pressure of fluid,
$\mathbf{n}$	unit vector normal to surfaces, positive outward,
$\mathrm{d}s$	differential surface area,
$\boldsymbol{\tau}$	local shear stress due to friction,
w.s.	wetted surface of container.

These forces can be computed by using the well-known momentum equation of fluid mechanics:

$$\mathbf{R} = \int\limits_{w.s.} p\mathbf{n}\mathrm{d}s + \int\limits_{w.s.} \boldsymbol{\tau}\mathrm{d}s = -\int\limits_{c.v.} \frac{\partial}{\partial t}(\mathbf{v}\rho)\,\mathrm{d}V - \int\limits_{inlet,\ outlet} [p\mathbf{n} + \rho\mathbf{v}\,(\mathbf{v}\mathbf{n})]\,\mathrm{d}s - \int\limits_{c.v.} \mathbf{g}\rho\mathrm{d}V \tag{3.2}$$

where

$\mathbf{g}$	acceleration vector due to gravity,
$\mathbf{v}$	velocity of the center of mass of the fluid,
ρ	density,
$\mathrm{d}V$	differential volume element,
c.v.	control volume,
inlet	inflow surface,
outlet	outflow surface.

By proper choice of control boundaries, the integrations in equation (3.2) over the inflow and outflow areas can be greatly simplified. Figure 2 shows the situation at feedwater pipe break.

By using the equation for the total mass flow rate

$$\dot{m} = \rho v A \tag{3.3}$$

we can apply equation (3.2) to the situation shown in Figure 2 for computing the resultant force acting on the reactor vessel. Fortunately, for a simple geometry such as that of a pipe with constant cross sectional area like that in Figure 2, the integrations in equation (3.2) can be simplified as

$$R_x = -\left[L\frac{d\overline{\dot{m}}}{dt} + (p_2 - p_a)\,A + \dot{m}_2 v_2\right] \tag{3.4}$$

where

$\overline{\dot{m}}$	average mass flow rate in the pipe. This can be computed as the sum of the mass flow rates in the feedwater pipe control volumes divided by the number of control volumes
$\frac{d\overline{\dot{m}}}{dt}$	can be computed numerically by RELAP 5 internal control components.

The first term in (3.4) is called wave force, and the second and third terms together are called the blowdown force.

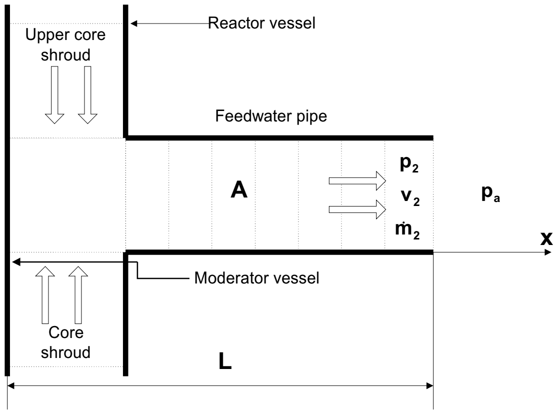

Figure 2. Detailed nodalization at feedwater inlet

The computed reaction force R_x can be correlated to the initial thrust, which is simply the break plane area multiplied by the initial pressure within the pipe. The thrust coefficient C_T is defined by

$$C_T = \frac{R_x}{p_0 A} \tag{3.5}$$

where A is the break plane area and p_0 is the initial pressure within the pipe. The theoretical maximum value is $C_T = 2.0$ which occurs at steady state frictionless flow of subcooled water.

4. Computational results

According to [7] it is a conservative assumption to assume that the pipe break happens in 1 ms, and the break flow area reaches its maximum at 10 ms. RELAP 5 uses Henry-Fauske's model [6] for two-phase critical flow calculations. The pipe break is modeled by opening a break-valve connected to the pipe. The break-valve area is assumed to increase linearly from zero to the full pipe flow area in 10 ms. The computed flow rate in Figure 3 starts at a negative value, which is the normal feedwater mass flux into the reactor vessel, and reaches its maximum slightly above 8 kg/cm^{2}s at 22 ms.

The initial pressure in the vessel is 7 MPa and the feedwater temperatures are assumed to vary between 453 – 473 K. The initial pressure in the pipe sinks very

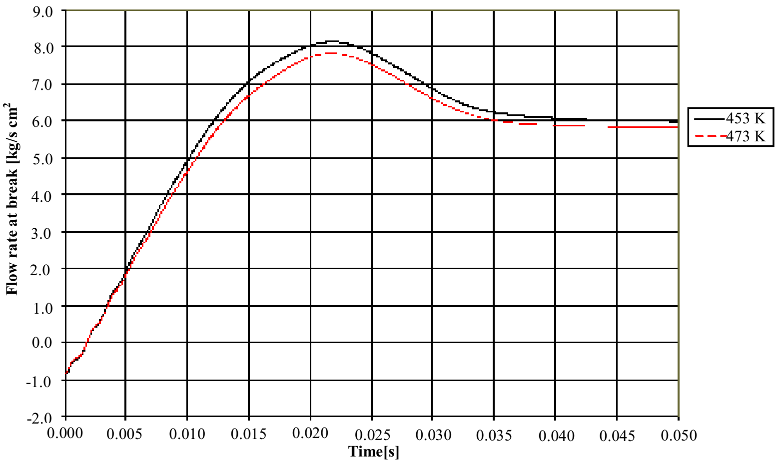

Figure 3. Break location flowrate at different water temperatures in the feedwater pipe

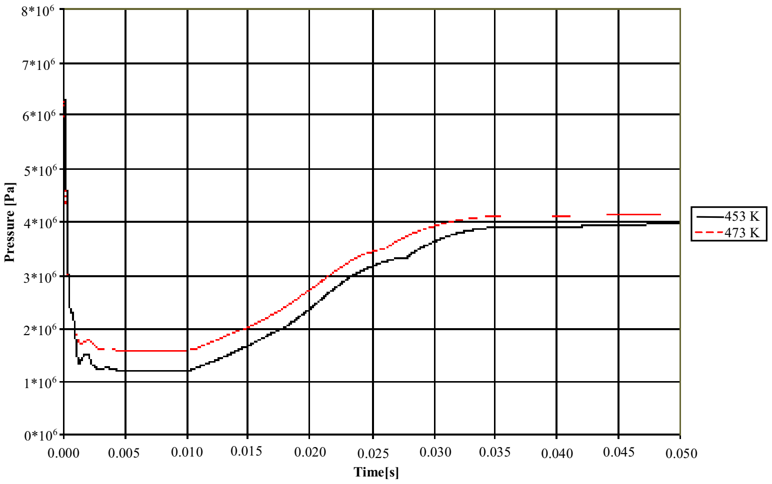

Figure 4. Pressure in the pipe at the break location, as function of time and water temperature

rapidly starting from the break location, as it is shown in Figure 4.

The computed forces (Figure 5) have an initial frequency, which is determined by the length of the remaining pipe attached to the vessel. These oscillations

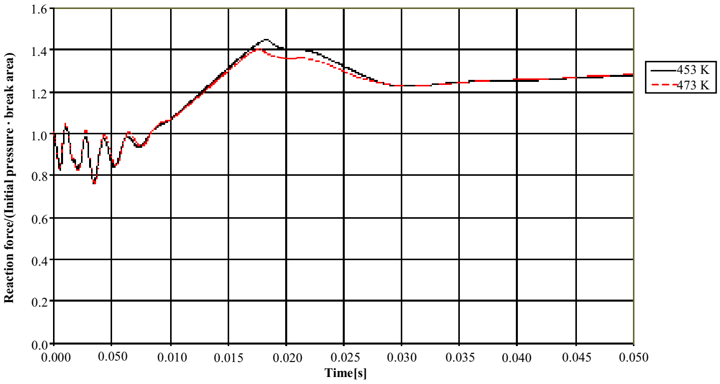

Figure 5. Computed thrust coefficient, C_T, as function of feedwater temperature and time

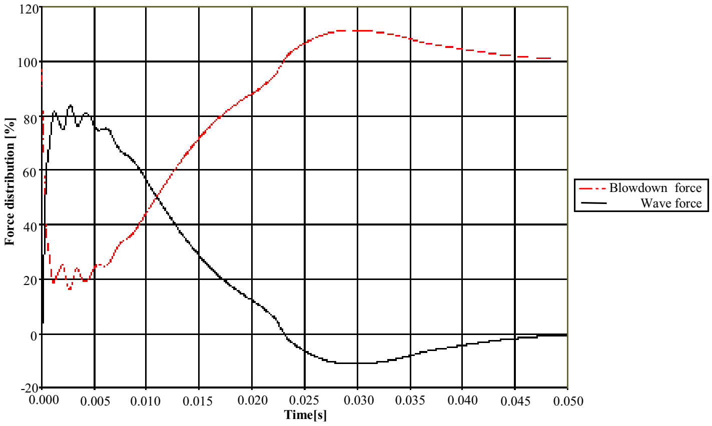

Figure 6. Distribution of the total force between "blowdown-" and "wave" forces as function of time

are attenuated very rapidly with the increasing void and decreasing speed of sound in the two-phase mixture. Finally Figure 6 shows the variations of the computed blowdown- and wave forces equation – see equation (3.4).

5. Conclusions

The paper demonstrates an application of the RELAP 5 code for computing global hydraulic loads due to a feed water pipe break at a nuclear boiling water reactor system. These computed hydraulic loads should be used for design of the reactor vessel and piping support structures. The computed loads have been evaluated against the theoretical maximum of such loads and are found to be within the theoretical limits.

This code has proven to be appropriate for calculation of hydraulic forces in such a situation.

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