Influence of seismic excitation on the drop time of control assemblies in PWR's

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Summary: In this paper the influence of seismic-induced vibrations on the drop time of control assemblies in a Pressurized Water Reactor (PWR) is investigated with the aid of numerical methods. This procedure is verified and qualified by a number of fundamental experiments. It is shown that the increase of the drop time due to seismic excitation is less than 1 s . This result remains valid for vibrations under broad variations of the main input parameters.

1. Introduction

Quick shutdown in a PWR is initiated by allowing the control assemblies on top of the pressure vessel to fall into the core by gravity. The drop time during normal operation is mainly influenced by the weight of the control assemblies, the counteracting velocity of the coolant flow and the friction forces between the moving parts and the control rod drive housing, whereas in the case of an accident, e.g. earthquake, an additional influence due to horizontal vibrations has to be considered.

Mutual impacts between the dropping control assembly and its surrounding structure tend to increase the drop time compared to the values known from normal operation.

The influence of these phenomena on an increase of the drop time can be, in principle, analysed by experimental or computational methods. Due to the complexity of the interactions between control assembly and the surrounding components of the Control Rod Drive Line (CRDL) experimental methods have been favoured up to now.

This paper shows that the drop of the control assembly in a PWR during a postulated seismic event can also be simulated by numerical methods.

It is shown that for the considered PWR geometry only an insignificant increase in the scram time (less than 1 s) must be expected as a result of the consideration of the seismic impacts, even in the case of a very severe and long lasting earthquake excitation.

Further it is demonstrated that this result is valid even for broad variations of the main input parameters.

2. Modelling

For the appropriate modelling of the motion of a control assembly during a seismic event (drop behaviour) we consider 2 groups of main influencing parameters.

Group 1:

- temperature and pressure of fluid
- fluid and mechanical forces acting on control assembly resulting from its vertical motion

The Group 1-parameters are relevant for normal operation.

Group 2:

- horizontal motion of CRDL-components and control assembly due to earthquake
- Coulomb friction resulting from horizontal impacts between CRDL-components and control assembly

The Group 2-parameters occur only during an earthquake.

In normal operation the drop of the control assembly is impeded by fluid and mechanical resistance forces resulting from the relative vertical motion between control assembly, fluid and the components of the CRDL.

It can be assumed that the acting forces which influence the control rod drop time during normal operational conditions do not change during a seismic event because the relevant parameters (temperature, pressure, mass flow, as built gaps) are not affected by a simultaneously occuring vibration.

Therefore these forces can be determined from drop-experiments performed under normal operation conditions.

Such drop experiments were executed with original control assemblies.

The drop curve resulting from such experiments is approximated by the solution of an appropriate differential equation which describes the drop behaviour of the control assembly at operating conditions. Hereby the group 1 parameters are directly determined. Details of this procedure are given in /1/. These group 1 parameters are direct input parameters to the calculation.

The group 2 parameters which are exclusively present during a seismic event are taken into consideration by an appropriate mechanical modelling.

The total model is shown in fig. 1. It consists essentially of an "inner structure", the dropping control assembly, and an "outer structure", which constitutes the different components of the CRDL. The motion of the "outer structure" is assumed to be given, i.e. possible influences on the motion of the "outer structure" exercised by feedback from the "inner structure" are assumed to be negligible and are not considered. Details are given in /1/. We consider now the impact force acting on a specific node of the "inner structure" at an arbitrary time. In order to determine this force the following calculational steps must be performed:

- for the specific node of the "inner structure" considered, the horizontal displacement of the corresponding neighbouring part of the "outer structure" is determined. This is done by linear interpolation between the excitation nodes of the "outer structure", where horizontal displacements are given.
- determination of the momentary gap between the considered node of the "inner structure" and the neighbouring part of the "outer structure" (depends on the vertical position of the node considered)
- determination of the local overlapping of "inner" and "outer" structure and calculation of the impact force. The impact force is calculated via a hypothetically defined surface stiffness. It can be shown, however,

that the total delay in the scram time is independent from the surface stiffness, if the surface stiffness is chosen large enough, which is the case for the real structure. This follows from the fact that the vertical deceleration effect is determined by the product of impact force and impact time rather than by the impact force itself.

The vertically acting friction force due to seismic effects is equal to the sum of all locally acting impact forces between "inner" and "outer structure" multiplied with friction coefficient μ.

Due to the extreme nonlinearity of the phenomena involved we use an explicit Runge-Kutta algorithm for integrating the equations of motion.

3. Results

In order to establish the validity of the calculation model described above, a series of experiments has been performed.

For one type of experiment (test T.I,.) a well defined displacement has been exercised on the top of the drive mechanism. This displacement was retained during the complete scram.

For another type of experiment (test T.II,.) the initial displacement of the drive mechanism was released when the scram was initiated so that the structure was caused to undergo eigenoscillations during the control rod drop.

Measured delay times and delay times calculated with the described model for these types of experiments are compared in the following.

Table I

Case	Δ_{Exp}	$\Delta_{\mu = 0.3}$	$\Delta_{\mu = 0.5}$
T.II,40	0	0,09	0,15
T.II,70	0	0,17	0,31
T.II,120	0,11	0,35	0,70
T.I,40	0,01	0,07	0,12
T.I,70	0,25	0,18	0,32

The meaning of the symbols is as follows:

T.II,70 ⟶ experiment of type II, initial displacement = 70 mm
$\Delta_{Exp.}$ ⟶ measured delay time (in s)
$\Delta_{\mu = 0.3}$ ⟶ calculated delay time with doefficient of friction $\mu = 0.3$

We identify from Table I that a coefficient of friction $\mu = 0.5$ covers conservatively all of the experimental results ($\mu = 0.5$ is therefore used later on). In particular, prolonged, so called "additional" scram times which characterize the effect of sinusoidal motions of the drive mechanism(test T.II), as they occur during a seismic event, are conservatively overestimated by the calculational model.

The model determined so far is now used to calculate the additional scram time for 2 typical seismic events. It is assumed that the scram is initiated 2 s after the beginning of the strong stage of the earthquake.

The used acceleration spectra at RPV support for the 2 seismic events (earthquake case I and case II) are shown in fig. 2.

The spectrum of case I shows a peak value at 10 Hz, case II shows 2 peak values at 4 Hz and 10 Hz, respectively.

Fig. 3 shows the calculated motion for the point 35 (control assembly driving rod) for seismic event case I.

From fig. 3 we identify that the vibration amplitudes of node 35 are limited up to 4.0 s by the relatively small gaps between the drive shaft of the control assembly and the drive mechanism. Due to the drop of the control assembly the gaps between node 35 and the neighbouring "outer structure" are changing drastically from 4.0 s onwards resulting in larger vibration amplitudes.

Fig. 4 shows the calculated total vertical force acting on the control assembly, resulting from the impacts between the control assembly including driving rod and the surrounding structure. We identify that impact friction forces are superimposed to the "usual" fluid and friction forces from normal operation.

For case I we have an additional scram time, due to the earthquake excitation, of 0,57 s and of 0,32 s for case II.

The calculation of case I includes an additional conservative assumption since we have considered a simultaneous break of the fuel assembly centering pins which results in a mutual displacement of fuel assembly top end piece and grid plate.

Both additional scram times are much smaller than 1 s.

4. Conclusions

A numerical model for the determination of the seismic-induced additional scram time of a control assembly in a PWR was established.

Its basic input parameters are determined from drop experiments performed at normal operation conditions with original control assemblies.

The horizontal properties of the vibration model were checked and verified by a number of fundamental experiments.

The additional delay time for seismic events was shown to be smaller than 1 s. This result is valid for broad variations of the coefficient of friction and acceleration response spectra.

5. References

/1/ J. Stabel, J.D. Kim, R. Holzer: Comp. Model to Determine the Influence of Seismic Excitation on the Drop Time of Control Rods in Pressurized Water Reactors; ICCM Tokio, 1986.

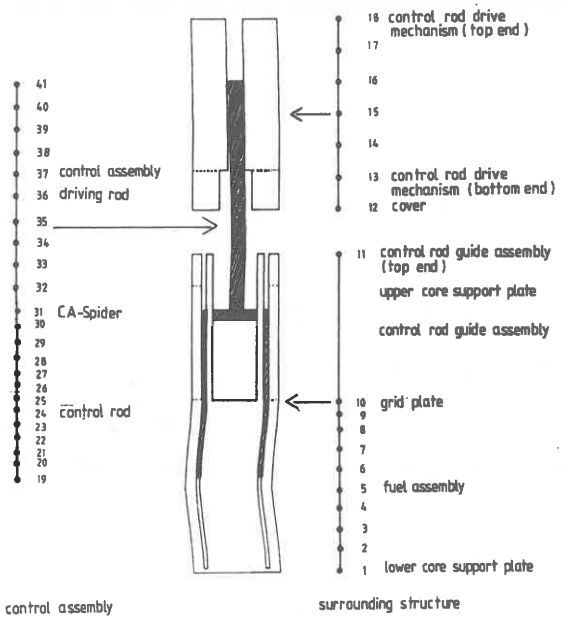

fig. 1: Scrammability-Model and State of Deformation for one specific point of time (seismic event)

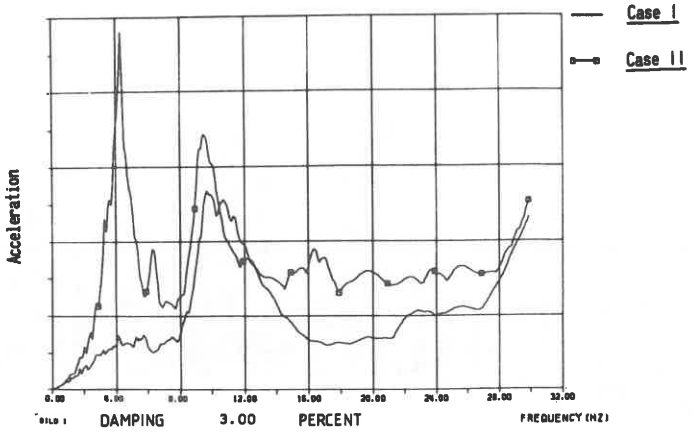

fig. 2: Acceleration Response Spectra at RPV support

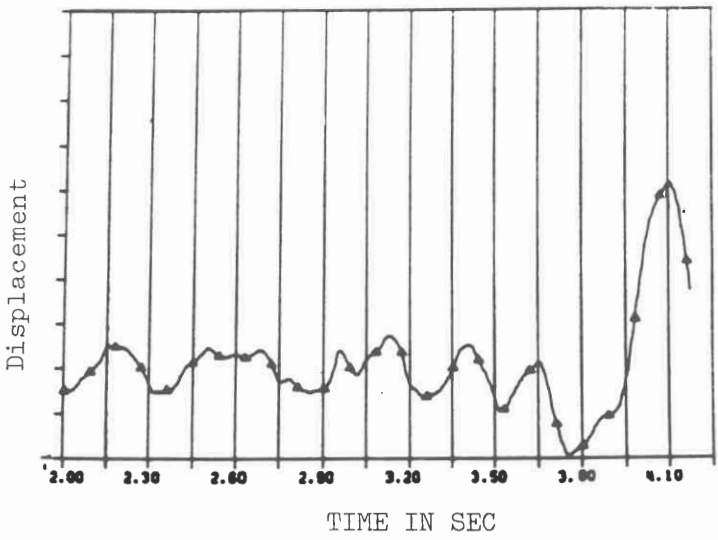

fig. 3: Displacements at node 35

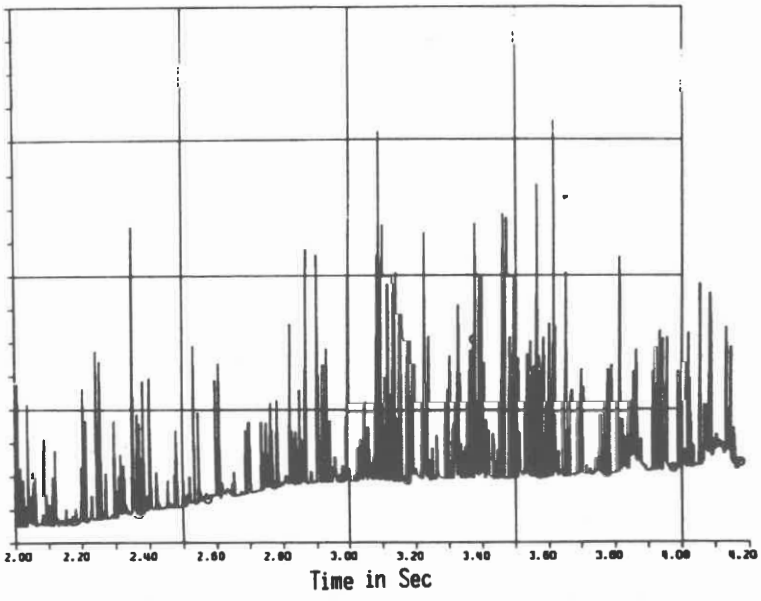

fig. 4: Total Vertical Force on Control Assembly for Earthquake Excitation