Possibilities of Decoupled Consideration of HDR Components

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SUMMARY

In assessing the safety of nuclear power plants it is necessary, to analytically evaluate the vibrational behavior of complex mechanical and structural systems. Calculating decoupled individual systems isolated from their surroundings constitutes a convenient way of providing meaningful results while keeping computational efforts within acceptable limits. During earthquake investigations performed as part of the HDR Safety Program, various mechanical systems were vibrationally excited both directly and indirectly through the containment structure. This was achieved by various excitation methods simulating characteristic features of earthquake vibrations /1/.

A systematic evaluation and detailed comparison of both measured and calculated vibrations taking into account interaction contribute to establishing a systematic means of determining the cases in which analytical decoupling of the individual systems is permissible. An overview of possible coupling among individual systems and of the kind of interaction to be expected will be presented schematically. Also additional conclusions regarding the extent to which HDR systems can be decoupled analytically will be drawn from measured and calculated results available. The investigations relate to coupling between the reactor pressure vessel and the core barrel as well as between the vessel and piping. Commonly used criteria for analytic decoupling of individual systems will be assessed on the basis of HDR results.

1. INTRODUCTION

The seismic design of nuclear power plants necessitates calculations of the dynamics in which, strictly speaking, the whole power station (i.e., building with soil, vessels, internals, pipework, components) constitute a large vibrational system. In the computational analysis of these comprehensive vibrational systems it is adequate for a reasonable assessment of the vibrational behavior to consider the individual systems separate from each other. Particularly striking advantages offered by this consideration of decoupled systems, include better transparency and handling of the models of computation, better assessment of computational results, and reduction in computer costs. These advantages must be paid for by a number of difficulties susceptible of affecting decisively the quality of the results of computations based on decoupled models of computation. These difficulties arise from the proper delimitation of sub-models, from the estimate of near-reality boundary conditions prevailing at the point of coupling and of interactions as well as from the definition of load introduction in terms of location and function.

In structural dynamics a distinction is made between mass coupling, damping coupling and spring coupling (or, in other words, coupling in terms of acceleration, velocity and amplitude). The main subject treated in these investigations is spring coupling. In the computational analysis of coupled vibrational systems the term "decoupling" is understood in most cases to mean a process in which by transformations of the equations of vibration the mathematical coupling terms are eliminated and the equations of movement can thus be solved in a "decoupled" manner. In contrast, the question of the capability of decoupling of the overall system cannot be seen in these studies under the aspect of a mathematical transformation of differential equations of subsystems vibrating at the same frequency or even under the aspect of mechanical decoupling of interconnected individual structures. The problem to be dealt with here rather consists in a systematic distinction of interconnected subsystems whose vibrational behavior permit to treat them separately in the computation, i.e. as "decoupled" systems. Depending on the nature of interconnected structures and the resulting vibrational modes, the systems can be decoupled if the adjacent system is completely neglected, or taken into account by substitute masses, or by a dynamically suited simplified substitute system.

Two types of coupling must be distinguished which are denoted vertical and horizontal coupling. Each of these types includes a primary and a secondary system.

To characterize in the description primary and secondary systems with a view to their capability of decoupling considered here, it is tolerable to restrict oneself to a two-mass vibration system. This is possible because a modal system can be assumed representing two modes each attributable to the primary system, on the one hand, and to the secondary system, on the other hand.

2. SYSTEMATIC OF ASSESSING THE VIBRATIONAL BEHAVIOR OF INTERCONNECTED SYSTEMS

The vibrational behavior of interconnected systems is determined both by external excitation and by the coupling induced reactions and interactions, respectively, of the subsystems.
The prerequisite of an independent consideration of a substructure connected to other structures is that the reactions from the adjacent structure is negligibly small or that they have no great influence on the vibration behavior of the structures considered. To allow a clear description of the couplings existing between the subsystems, a systematic was elaborated to assess the vibrational behavior of the primary and secondary systems. Assuming that the primary system is subject to forced excitation the primary system is attributed to a category of different degrees of coupling taking into account the coupling effects. This gives the systematic shown in Fig. 1 for assessing the vibrational behavior of systems interconnected by spring coupling.

3. EVALUATION OF RESULTS OBTAINED AT HDR

With the help of computed and measured results from HDR earthquake studies the vibrational behavior of some HDR components was investigated and, whenever possible, compared with known rules and criteria applied to assess the capability of subsystem decoupling. The studies related to the following HDR subcomponents: reactor building (RGE), reactor pressure vessel (RDB) inclusive of core barrel (KM) and the two piping systems primary steam line (PDL) and recirculation loop (URL).

3.1 Vertical Coupling

RDB-KM (load case: shaker RDB closure head, excentricity 2.86 kg m, without water)

The comparison of the frequencies obtained at the reactor pressure vessel with and without core barrel makes evident the great influence exerted by the core barrel on the vessel. Whilst for the reactor pressure vessel without core barrel the orthogonal RDB modes Nos. 1 and 2, respectively, have been found to be 15.5 Hz, the RDB/KM modes Nos. 1 and 2, respectively, are approx. 12.3 Hz and the RDB/KM modes Nos. 3 and 4, respectively, 16.2 Hz; this is due to the connection between vessel and core barrel (see Fig. 2). The core barrel in this case acts primarily as an added mass and thus causes a reduction in the frequency determined for the vessel without core barrel from 15.5 Hz to 12.3 Hz. The RDB/KM modes Nos. 1 and 2, respectively, at 12.3 Hz thus correspond to the RDB modes Nos. 1 and 2, respectively, of the vessel without core barrel at 15.5 Hz whilst the RDB/KM modes Nos. 3 and 4, respectively, at 16.2 Hz correspond to the modes Nos. 1 and 2, respectively of the non-connected core barrel. The modeshapes of interconnected subsystems determined from the measured values (Fig. 5) show that both subsystems have suffered from bending deformations and, consequently, an "RDB" or "KM" mode can no longer be assumed for the interconnected systems but rather a common RDB/KM mode. However, for the sake of clarity, the term RDB or KM mode will be used in the discussion of excitation by shaker.

In case of excitation by shaker at the top of the vessel both an excitation of the RDB/KM modes Nos. 1 and 2, respectively, (12.2 Hz) and an excitation of the RDB/KM modes Nos. 3 and 4, respectively, (16.3 Hz) are visible at the core barrel reference point (Fig. 3). The same conditions are found to apply at the vessel reference point. Since in all modeshapes both components participate to a more or less extent (bending deformation), an interaction must be assumed to exist between the core barrel and the reactor pressure vessel. This implies a third degree of coupling. Therefore, computation of the subsystem as a decoupled system cannot be performed.

Calculated results are available for a model consisting of reactor pressure vessel and core barrel whilst the two pipeworks have not been taken into account. The results obtained with this model (in case of forced excitation) by shaker allow to draw the conclusion also reached in the measurement that a third degree of coupling prevails (see Fig. 4).

Influence of Water Charge (load cases: shaker RDB with KM, with and without water charge)

Already the modeshapes of system without or with water charge (filling level 6 m) (see Fig. 5) determined from the measured values make evident the difference in the natural vibration behavior and hence coupling behavior of the reactor pressure vessel (primary system) and core barrel (secondary system). It is obvious from the comparison with calculated modeshapes and natural frequencies that these differences cannot be exclusively due to the additional water charge (Fig. 6). Whilst in a model "A" only the real water mass was distributed as an additional mass between the reactor pressure vessel and the core barrel, the model "B" takes into account a fluid/structure interaction via supplementary fluid elements by which "virtual" masses are added

to the external diagonals of the mass matrix. The good agreement of the modeshapes and natural frequencies calculated with model "B" with the measured results clearly indicates the occurrence of fluid/structure interaction in the real system.
The modeshapes of the reactor pressure vessel with core barrel and water charge (see Fig. 5) must be assigned to a second degree of coupling regarding the modes 1 and 2, respectively, and to a first degree of coupling regarding the modes 3 and 4, respectively. The results of computation obtained with model "B" show that in this case a computation will not be sufficient which takes into account solely the mass added although only a first degree of coupling prevails for the first and second modeshapes respectively.

3.2 Horizontal Coupling

RDB-PDL (load case: shaker RDP closure head, excentricity 2.86 kg m, without water)

The RDB is considered to be the primary system. The PDL is considered to be the secondary system.

At the closure head of the vessel an resonancepeak can be noticed only in the first bending mode of RDB/KM (first and second modes, respectively) (12.3 Hz) and in the higher-modes (Nos. 3 and 4, respectively) (16.2 Hz) (see Fig. 7). At the primary steam line a very pronounced resonance peak occurs at the RDB/KM mode No. 1 (12.3 Hz) in addition to the PDL mode No. 4 (9.3 Hz).
This result indicates a first degree of coupling at 12.3 Hz and a second degree of coupling at 9.3 Hz. The second degree of coupling at 9.3 Hz remains negligibly small here as regards its reactions on the RDB. Under these special conditions computations can be made assuming decoupled systems in such a way that the response at RDB is applied to the nozzle as an external excitation of the PDL.

In a second experiment the PDL was exposed to direct excitation. This means that now the PDL is to be considered as the primary system and the RDB as the secondary system.

PDL-RDB (load case: shaker PDL, excentricity 0.52 kg m, without water)

The PDL is considered to be the primary system, the RDB is considered to be the secondary system.

At the PDL resonance peaks are observed in the PDL mode No. 2 (8.2 Hz) and PDL mode No. 4 (10.2 Hz) (see Fig. 8). A reaction at RDB is negligible at these frequencies.
For this reason, the reactor pressure vessel must be considered as practically rigid relative to the pipework. Consequently, the pipework (primary system) vibrates independent of the vessel which, being the secondary system, is practically rigid. A zero degree of coupling prevails. This leads to the conclusion that for the computation-based consideration of the primary steam line decoupling of the reactor pressure vessel is feasible, which in this case is substituted by fixed clamping of the pipework.

4. RESULTS OF THE HDR-SPECIFIC EVALUATIONS

In addition to the studies described in this paper, similar evaluations have been made for other HDR systems under different experimental conditions. The individual results of evaluations concerning decoupling cannot be generally transferred. But assignment of the currently used criteria of coupling to the HDR structures (see Fig. 9) is possible through an assessment of the evaluation-results. Analysis of the vibrational conditions found and their classification within the system of degree of coupling described above permit a specific judgement to be made of the simplifications by which computation with decoupled systems is feasible. The general results will be published in a technical report by the Karlsruhe Nuclear Research Center.

REFERENCES

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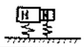
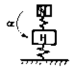
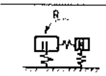
Degree of Coupling	Kind of Coupling		Description
	Vertical	Horizontal	
0. degree	H = primary system N = secondary system R = reaction W = interaction		Primary system vibrates at resonant frequencies. Secondary system not affected by primary system
1. degree			Primary system vibrates at resonant frequencies. Forced vibrations of secondary system at resonant frequencies of primary system.
2. degree			Forced vibrations of primary system. Secondary system vibrates at resonant frequencies
3. degree			Primary and secondary systems vibrate at common resonant frequencies

Fig. 1. Definition of degrees of coupling.

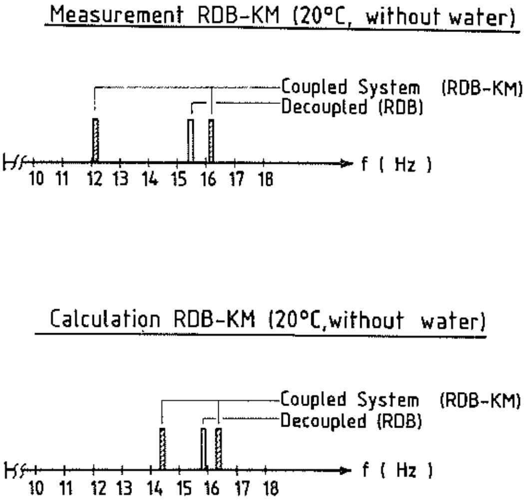


Fig. 2. Measured and calculated natural frequencies of RDB and KM.

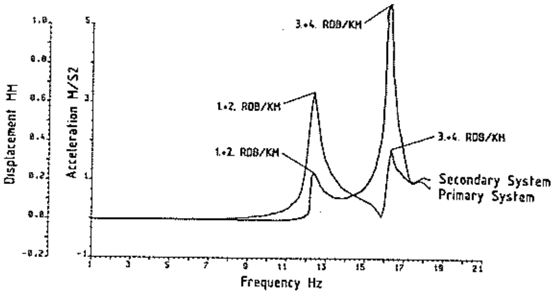


Fig. 3. Responses measured at RDB (acceleration) and at KM (displacement) during excitation by shaker at RDB.

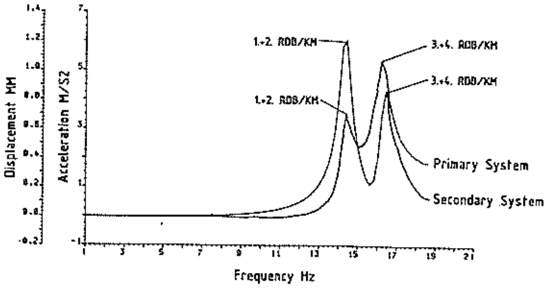


Fig. 4 Responses calculated at RDB (acceleration) and at KM (displacement) during excitation by shaker at RDB.

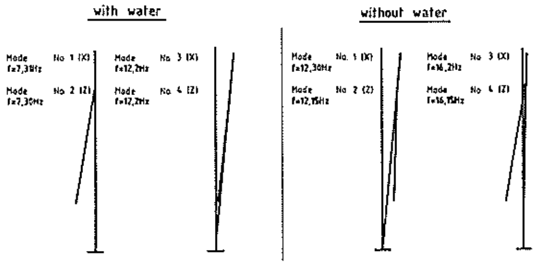


Fig. 5. Modes measured at RDB with KM (20 °C, with and without water).

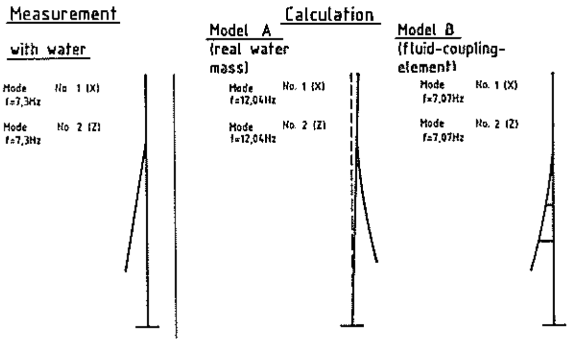


Fig. 6. Intercomparison of measured and calculated modes of RDB with KM and water filled.

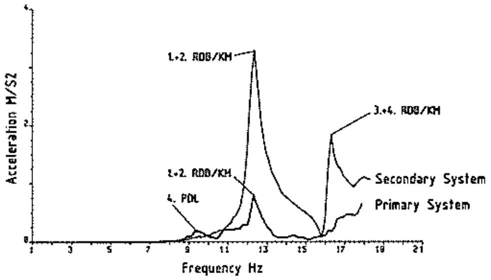


Fig. 7. Responses measured at RDB and at PDL during excitation by shaker at RDB.

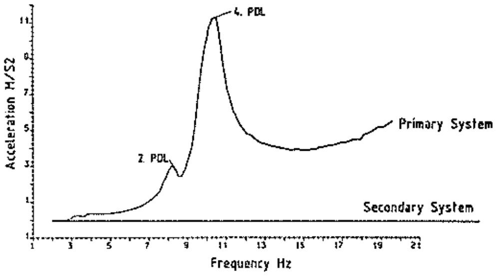


Fig. 8. Responses measured at RDB and at PDL during excitation by shaker at PDL.

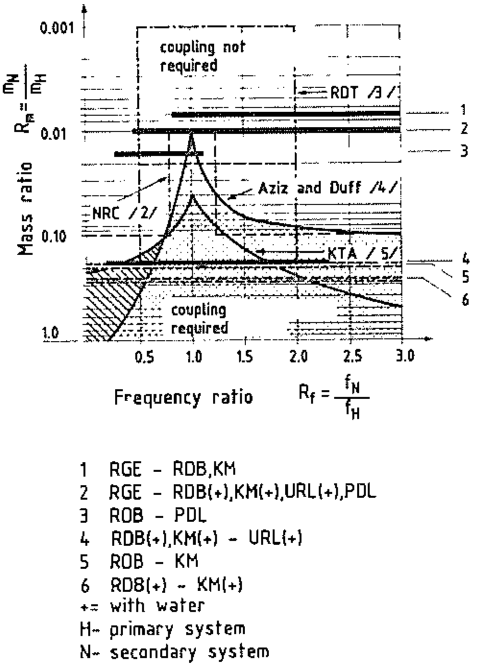


Fig. 9. Assignment of HDR systems to the usual coupling criteria.