Assessment of Coupling Effects of Coolers and Piping Systems

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SUMMARY

In the dynamic analysis of large systems there is a great incentive to perform the calculations separately for smaller, decoupled subsystems. This simplification has to be justified, at best by using appropriate decoupling criteria. In practice, however, this procedure is difficult to accomplish thoroughly due to the unsatisfactory state-of-the-art at present, as shown in this paper on the basis of two investigations.

In these investigations (see A and B below) linear elastic FEM-calculations have been carried out for both the large joint (coupled) systems and the decoupled subsystems. The resulting coupled and uncoupled loads at significant nodal points are evaluated.

In investigation A which deals with coolers and connected piping systems it is shown that an uncoupled analysis of the subsystems and a superposition of the influence of the piping systems to the coolers will yield adequate loads at the supports and the nozzles.

The investigation B for piping systems with different diameter ratios of the main system to the subsystems leads to the following results: Uncoupled analysis for the main system without consideration of any effects of connected subsystems results in a satisfactory accuracy only for diameter ratios higher than 3:1; the comparison of the coupled and uncoupled analyses for diameter ratio of 2:1 shows a necessary correction factor for the uncoupled analysis of about 7.

1. Introduction

In the dynamic analysis of large systems it is favourable to divide in smaller subsystems and to perform the calculations separately. It is, however, necessary to take correcting measures for these uncoupled subsystems to get conservative results compared to the complete analysis of the coupled system. The purpose of the following investigations A and B (chapter 3. and 4.) on two different models is to demonstrate that an uncoupled analysis is permissible even if the decoupling criteria of common guidelines are not fulfilled, provided a correction factor or a superposition of the uncoupled subsystem loads is taken into account.

2. Comparison of Coupled and Decoupled Analysis for Coolers and Connected Piping Systems (Investigation A)

2.1 Background

"Decoupling" is generally made permissible in practice by means of structural measures, for example, supporting the coolers near the piping connection.

Where the structural conditions make this decoupling impossible, compliance with the decoupling criteria as they are defined in the form of mass and frequency conditions in the relevant literature must be investigated. An attempt is made on the basis of the investigation A as described below.

2.2 Calculation and Results for Coolers and Piping Systems

Analyses were performed for two coolers (see Fig. 3) and eight pipe system lines connected to these coolers, both separately and in a joint computation model. The individual systems were represented by computation models of between 17 and 56 nodal points; the overall systems consisted of 297 nodes. A schematic of the finite element-model is shown in Fig. 1. The mass ratio between cooler and the largest connected pipe was 0.55 and the most unfavourable relevant frequency ratio was almost 1 (resonance) not allowing for decoupling based on the usual 2-mass-oscillator-criteria.

The dynamic loads for the individual subsystems and coupled system were determined by means of response spectrum modal analysis by using a typical response spectrum as given in Fig. 2. The loads on the cooler supports and at the transition between the nozzles and the cooler shell, as well as the loads at the weld between the pipe and the nozzle, were evaluated (see Fig. 3). The results of the uncoupled analysis of the piping systems have been superimposed statically on the uncoupled cooler loads to take into account the influence of the connected pipings. A comparison of the results showed (Fig. 3) that only in one of the examined directions (X3) were the loads from the coupled analysis greater than those from the uncoupled analyses for the individual systems; in the other directions the loads were reduced by the coupling, in some cases considerably. It is therefore preferable to use not the load differences but the difference in reference stresses as the criterion for judging whether a coupled analysis of the subsystems is permissible. This resulted in a maximum stress increase of 12 % in one of eight nozzles analyzed; on average there was a stress reduction of 8 % over all nozzles.

This investigation shows, that the common decoupling criteria, based on frequency-shifting, are too restrictive. The calculated overstress (12 %) is in practice not important, because loads other than dynamic loads (e.g. operation loads) often have a larger contribution to the total stresses.

3. Coupling of Piping Systems, Estimation of Load-Factors to Account for Neglected Subsystems (Investigation B)

3.1 Background

For the planning of nuclear power plant main piping systems accompanying calculations are necessary to account for the dynamic loads (e.g. earthquake). There is a great incentive to ignore the adjoining smaller piping systems in these FEM-calculations since at this early stage subsystem design has normally not yet been completed and calculation costs have to be kept low.

In this investigation B the influence of subsystems having smaller diameters than the main piping system (diameter ratios 2:1 and 3:1) is analyzed, i.e. a total load factor is estimated by which the dynamic decoupled loads of the main piping system have to be multiplied to obtain the corrected coupled loads.

3.2 General Description of the Method

In order to arrive at a reliable estimate of this total load factor above, covering the abundant variety of different piping systems, a versatile procedure is adopted to solve this special coupling/decoupling problem as follows:

a) Representation of the complicated piping systems in their as-built condition by a variety of simplified setups comprising the connection of the two systems and realistic supports (see chapter 3.3)

b) Splitting of the total load factor in two components, taking into account the modal properties and the shape of the response spectrum (see chapter 3.4)

c) Final check of the results by means of a full calculation of an as-built piping system (see chapter 3.5)

3.3 Description of the Simplified Setups

Because of the high potential of cost reduction (about 50 %) for the accompaning calculations, as a first approach this investigation started for piping systems having low diameter ratios 2:1. For this selection a great abundance of different piping systems has to complied with. A carefully selected variety of simplified setups has been created, representing these as-built systems (in accordance with item a) of chapter 3.2). For the main simplified piping system (RUN) an outer diameter of 323.9 mm and wall thickness 10 mm has been selected. The corresponding values for the smaller piping system (BRANCH) are 168.3 mm and 6.5 mm. For both systems realistic supports have been selected. The simplified eight setups include two different geometries and consists, for each geometry, of four configurations being characterized by the lowest eigenfrequencies f_r and f_b of the decoupled systems RUN and BRANCH:

- 2 dimensional geometry K in configurations $\boxed{\text{K3}}$, $\boxed{\text{K5}}$, $\boxed{\text{K7}}$, and $\boxed{\text{K6}}$ as shown in Fig. 4a
- 3 dimensional geometry Z and configurations $\boxed{\text{Z8}}$, $\boxed{\text{Z3}}$, $\boxed{\text{Z7}}$, and $\boxed{\text{Z6}}$ as shown in Fig. 4b

3.4 Calculation and Results for the Simplified Setups

For these simplified setups FEM-calculations have been carried out by means of the response spectrum modal analysis and using a simplified and broadened earthquake response spectrum as given in Fig. 5. In Fig. 5 the eigenfrequencies for both decoupled and coupled systems are marked also by the versatile flag-symbols forming a complicated pattern of the frequency-shifts. The essential aspect of this frequency pattern is given, however, by the position of the eigenfrequencies relative to the peak region of the response spectrum: only for the configurations $\boxed{K6}$ and $\boxed{Z6}$ the number of eigenfrequencies in the peak region is constant for both cases "decoupled RUN" and "coupled systems", whereas for the remaining six configurations the coupling results in an increase of frequencies in the peak region.

This behaviour has a strong influence on the <u>t</u>otal load factor k_t relating the loads of the RUN-supports (see chapter 3.1)

$$k_t = \frac{\text{"coupled systems"}}{\text{"decoupled RUN"}} \qquad (1)$$

as can be seen in Fig. 6: apart from $\boxed{K6}$ ($k_t \approx 0{,}9$) and $\boxed{Z6}$ ($k_t \approx 1{,}0$) for the remaining configurations k_t is in the range approximately from 2.7 up to 4.5. It is, therefore, suggested to split up the total load factor k_t

$$k_t = k_m \circ k_l \qquad (2)$$

in two components (in accordance with item b) of chapter 3.2). The factor k_m is determined by the <u>m</u>odal properties only and k_l is governed by the "effective" shape of the <u>l</u>oad (response spectrum). In Fig. 6 estimated values of k_m are given also by using the reasonable relations

$$k_m = \frac{k_t}{k_l} \qquad \begin{array}{lll} k_l = 1 & \text{for } \boxed{K6} \quad \boxed{Z6} & (3.1) \\ k_l = \dfrac{32.4}{9.58} & \text{for } \begin{array}{c}\boxed{K3}\\\boxed{Z8}\end{array} \begin{array}{c}\boxed{K5}\\\boxed{Z3}\end{array} \begin{array}{c}\boxed{K7}\\\boxed{Z7}\end{array} & (3.2) \end{array}$$

showing a narrower bandwidth in the range approximately from 0.8 to 1.3 for now <u>all</u> the configurations. The relation (3.2) especially $k_l = 32.4/9.58 = 3.38$ is based on the relative "stair-height" most configurations have to overcome, while "climbing" from "decoupled RUN" to "coupled systems". On the other hand in (3.1) the load influence is negligible.

In Fig. 6 only the average load factors are shown, extreme values are ranging, however, approximately up to 7 for k_t and up to 2 for k_m.

3.5 Results of all Calculations

It is not recommended to ignore smaller piping systems having half the diameters (2:1) because the correcting factor k_t has a high upper limit and the uncertainties involved. This proposal is based on the results of the above analysis on the simplified setups and has been confirmed by calculations of a realistic as-built piping system where some extreme values of about 4 do occur for k_t. Thus following the final check procedure (item c) of chapter 3.2) calculations on a realistic piping system having diameter ratio 3:1 have been carried out in addition, where the correcting factor k_t is approximately 1.

It is, therefore, permissible to neglect piping systems having one third of the diameter (3:1).

4. Conclusions

The investigations, performed on an actual system, showed that the decoupling guidelines, which define a difference in frequency as the criterion for permissibility and are generally determined by means of two mass oscillators, are very restrictive. In addition it is difficult to apply the decoupling guidelines in the case of a complex structure, as each mode and each direction has to be dealt with separately.

It seems preferable to define the difference in load and not the difference in frequency in order to determine whether a decoupled analysis is permissible. However, this means that decoupling guidelines have to be stipulated separately for each load case (e.g. earthquake, aircraft crash).

Since solving the decoupling problem by means of analysis is very involved, and general rules for the decoupling are extremely conservative, it seems more practicable to solve this problem by means of structural measures wherever it is possible.

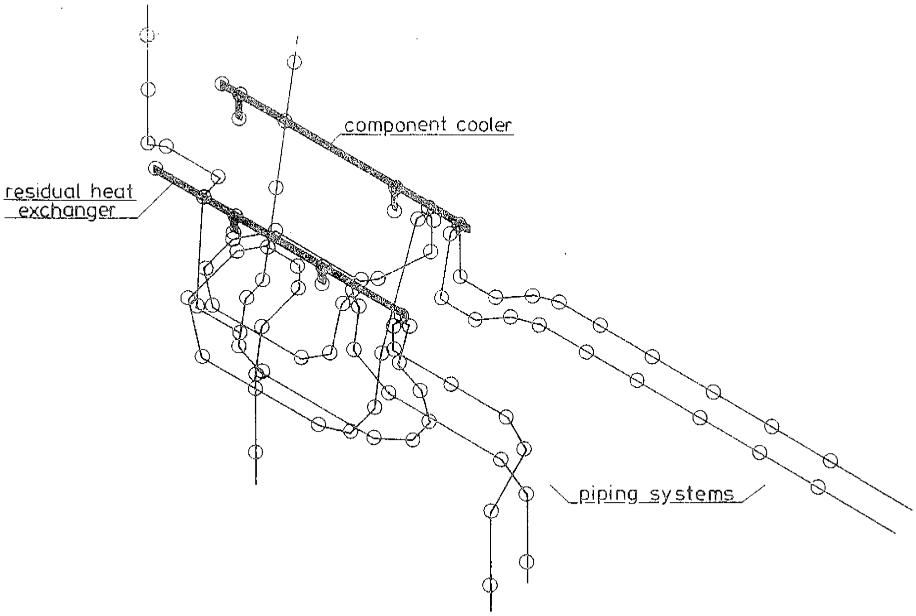


Fig.1 Schematic of Finite-Element-Model of Coolers and Part of Connected Piping Systems

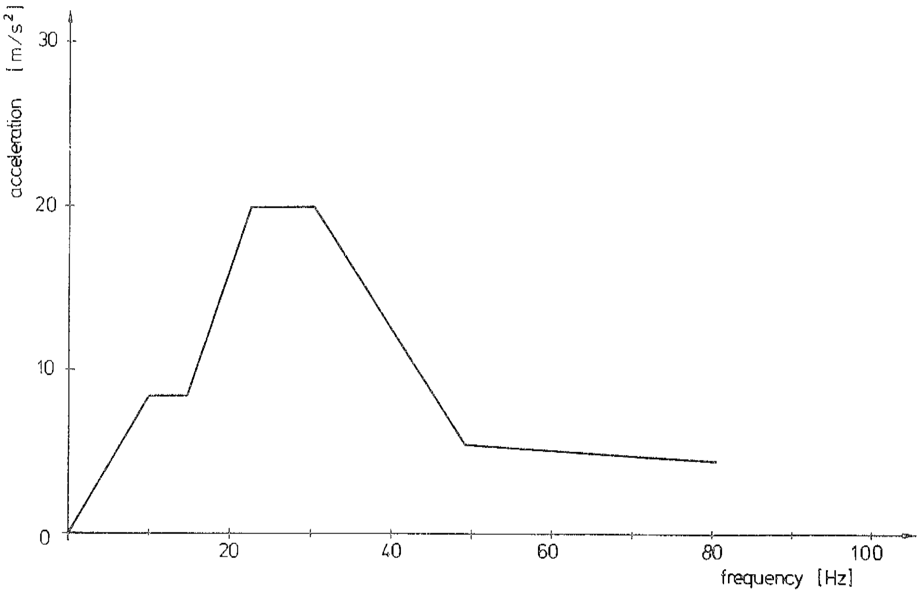
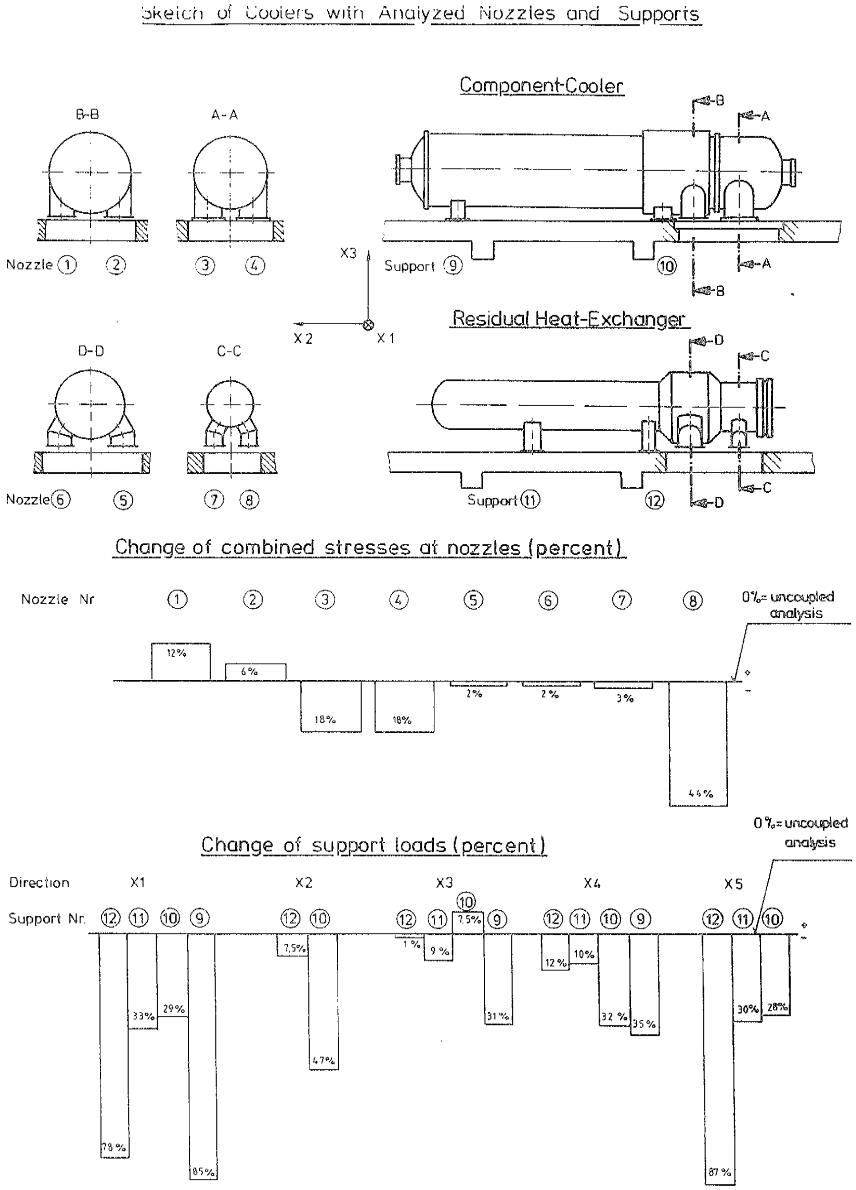


Fig.2 Typical Response Spectrum for Analysis of Coolers and Piping Systems


Sketch of Coolers with Analyzed Nozzles and Supports

Change of combined stresses at nozzles (percent)

Change of support loads (percent)

Fig.3 Comparison of Coupled versus Uncoupled Analyses of Coolers and Connected Piping Systems

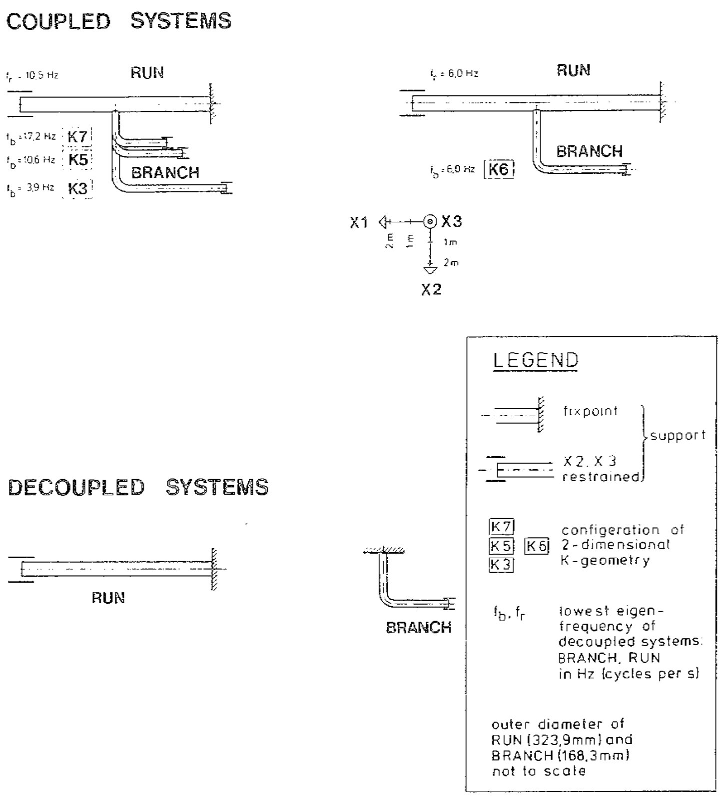


Fig.4a Sketch of 2-Dimensional Simplified Setups Representing Large Piping Systems

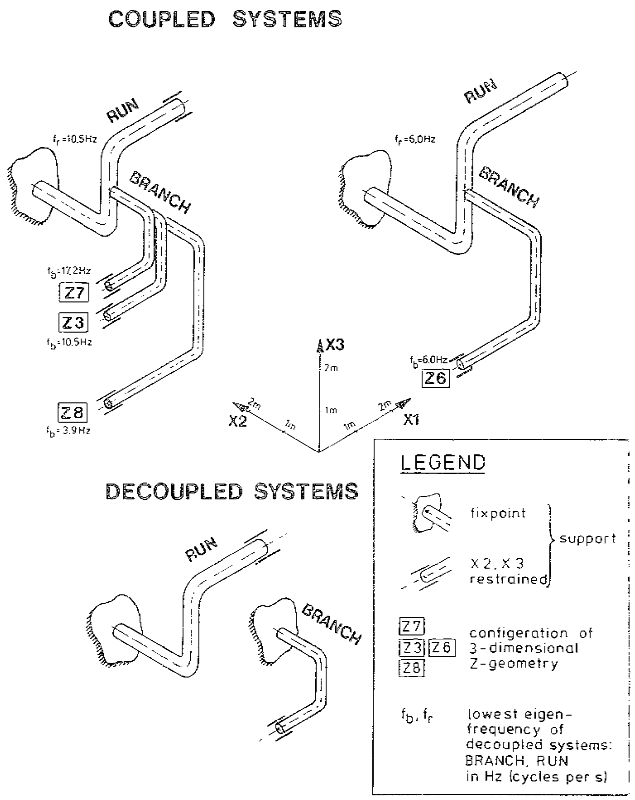


Fig.4b Sketch of 3-Dimensional Simplified Setups Representing Large Piping Systems

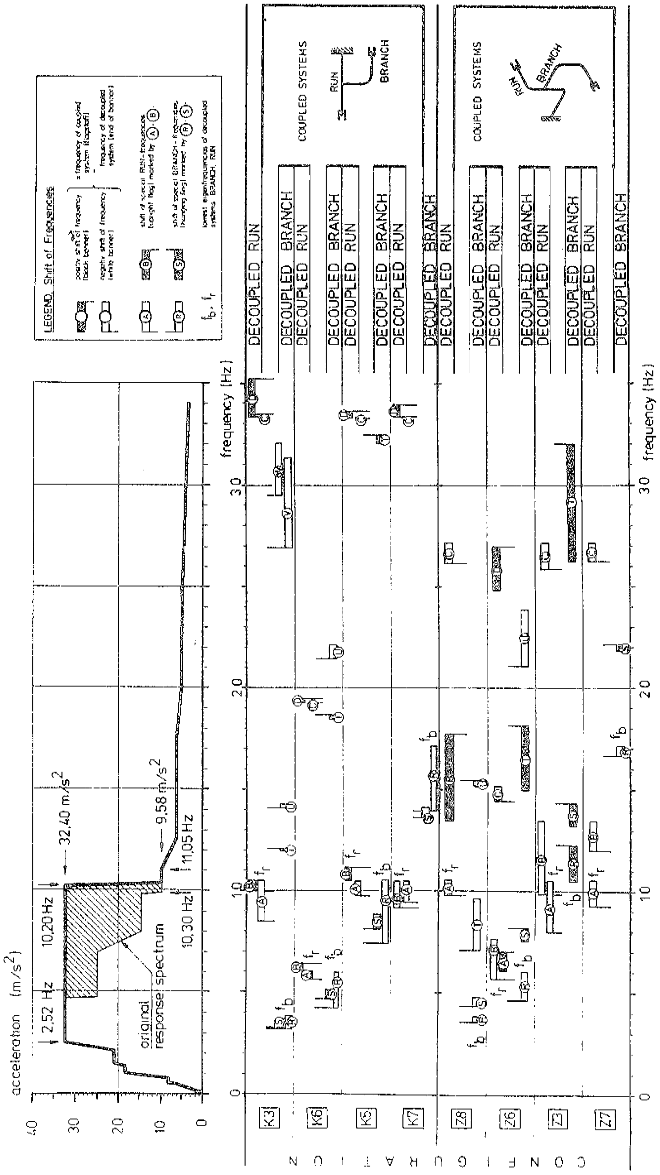


Fig.5 Frequency Shifts of Simple Pipe Configurations and the Positions relative to the Response Spectrum Peak Region

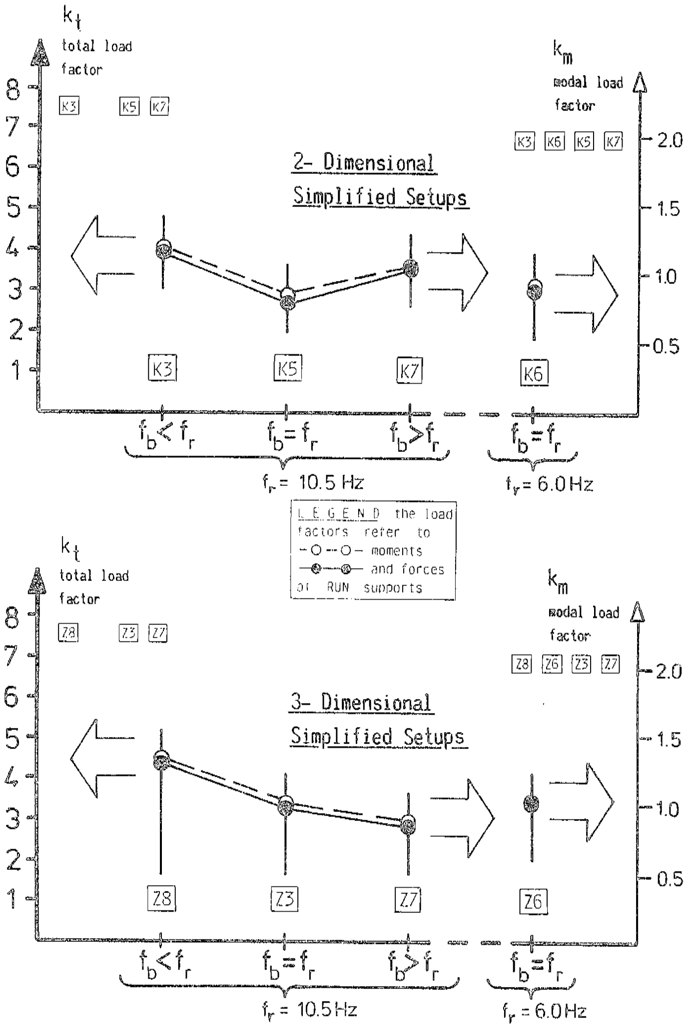


Fig.6 Average Correction Factors k_t and k_m to Account for the Coupling Influence of Simple Pipe Configurations