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Criteria for Decoupling and Overlap of Piping Systems — Procedure and Applications

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ABSTRACT

The dynamic analyses performed to demonstrate the integrity of the nuclear power plant piping systems require the mathematical modeling of all interconnected pipes. A such coupled analysis is not only uneconomical, but probably impossible, for computational, chronological and economical reasons. Methods for numerical decoupling of parts of the same piping system have been developed.

The proposed "overlap" method consists of a mutual (simplified) representation, upstream and downstream from the theoretical decoupling point, of the interconnected piping systems in the model of each other.

The validity of this approach is discussed in theoretical investigations based on simple beam models.

1. INTRODUCTION

Nuclear power plant piping systems are subjected to a wide range of anticipated and postulated dynamic excitations. The dynamic analyses performed to demonstrate the integrity of those piping systems require the mathematical modeling of all interconnected pipes. However, computational difficulties (limitations to the size of the models in the available computer programs, loss of numerical significance due to the stiffness and mass dissimilarities), chronological gap between the design and analysis of large bore piping systems, and the routing of small bore -site routed- piping, and dramatically increasing costs (fabrication, erection, and operation) of artificial anchor points (additional fixed points used to decouple piping systems in manipulable stress isometrics), evidence the need for numerical decoupling criteria and methods.

2. DECOUPLING CRITERIA

In the last decade, criteria for systems/subsystems decoupling have been developed (Ref. 1 to 7). Those criteria are usually based on theoretical simple models (SDOF-SDOF), or (IBRAHIM /7/) on the modal characteristics of the header system and branch subsystem. They address only the problem encountered in the modeling of the header or large diameter piping from which small diameter branch lines should be decoupled. No guidance is provided for the qualification of the subsystem itself, nor criteria for numerical decoupling of large piping systems in manipulable stress isometrics.

3. OVERLAP TECHNIQUE

When "erasing" some part of the piping system from a model, the dynamic influence of the deleted part upon the system being kept and analysed must be evaluated ; if the dynamic influence of a subsystem likely being handled separately cannot be neglected, the pure decoupling is not allowable.

The overlap technique proposed as an alternative to the decoupling, consists of a mutual, somewhat simplified representation of the physically interconnected piping systems in the model of each other, upstream and downstream from the theoretical decoupling point.

This "overlap" zone, included in a system to represent a decoupled part, extends at least to the node at which each of the three translational directions of motion has been blocked at least twice : the aim is at filtering the dynamic influence of downstream piping through a - not uniquely located - full anchor, i.e. blocking of the six (translational + rotational) degrees of freedom.

If the connected line, the influence of which is represented by overlapping, is a smaller diameter (but too large to allow full decoupling : typically in the bending inertia range of 5 to 25 times smaller than the run) branch line, the overlap is stopped at the first three-way stop (possibly split in several one - or two - way stops).

Similarly, the influence of the header or large diameter piping upon the response of a small branch line decoupled using criteria as per Ref/1/to/7/, is taken into account through a simplified modelization of the large bore piping into the small bore system model, up to the second stop in each translational direction, upstream and downstream from the branch point.

4. JUSTIFICATION OF THE OVERLAP TECHNIQUE

No formal demonstration exists to assess the theoretical background of the proposed technique. The following analysis, based on the simple continuous beam models (Fig.1) emphasizes the fading of the response to the motion of a single support point when passing through other support points in the same global direction.

We consider a uniform, infinitely long beam, supported at equally spaced points ; for simplicity, one single direction of excitation is examined. For symmetry reasons, the semi-infinite beam (Fig.2) is equivalent to the first model (Fig.1).

We shall investigate whether the influence of the motion of the origin (Point 0); assuming an independent support motion of all support points, remains significant beyond the second transverse support point.

The response in a particular mode i due to the motion of a particular support point j may be written (CLOUGH/8/),

$$\underset{\sim}{u} = \Gamma_{ij} \, \underset{\sim}{\phi}_i \, S_a \qquad , \quad \Gamma_{ij} = \underset{\sim}{\phi}_i^T \, \underset{\sim}{m} \, \underset{\sim}{u}_{jb} \, . \qquad (1)$$

where Γ_{ij} is the modal participation factor of the mode i due to the motion at j; $\underset{\sim}{\phi}_i$ is the modal vector; S_a is the spectral acceleration at the modal frequency; $\underset{\sim}{u}_{jb}$ is a displacement vector obtained by statically displacing the j-th support point in the direction of excitation (influence function) .

Assuming a uniform spectral acceleration S_a, the response ratio, i.e. the ratio of the maximum response in a span, to the same parameter in the first span, is determined by the influence function.

We define the following non dimensional variables :

$\xi(x)$ ($= y / l$) , non dimensional deflection,
ξ_j , deflection at the j-th support point,
$\theta(x)$, rotation,
θ_j , rotation at the j-th support point,
$\mu(x)$ ($= M / EI$) , non dimensional bending moment,
μ_j , moment at the j-th support point,
ρ_j ($= Rl / EI$) , non dimensional support reaction at the j-th support point

wherein

l is the span length,
E is the Young's modulus,
I is the moment of inertia.

We assume a transverse displacement ξ_0 of the support 0. Using the three-moment equation (ROARK/9/), yields the following equations :

$$
\begin{aligned}
4\,\mu_0 + 2\,\mu_1 &= -12\,\xi_0 \,, \\
\mu_0 + 4\,\mu_1 + \mu_2 &= 6\,\xi_0 \,, \\
\mu_{n-1} + 4\,\mu_n + \mu_{n+1} &= 0 \,, \quad n > 1 \,.
\end{aligned}
\qquad (2)
$$

The recurrence equation (2_3) may be rewritten

$$
\mu_n = \cfrac{-1}{4 - \cfrac{1}{4 - \cfrac{1}{4 \ldots}}} \mu_{n-1} = -\mu_{n-1} F, \qquad (3)
$$

wherein the continued fraction F may be evaluated, we find

$$F = 2 - \sqrt{3} \,, \quad 1/F = 2 + \sqrt{3}$$

and using Eq $(2)_{1-2}$,

$$
\begin{aligned}
\mu_0 &= -6\,\xi_0\,(\sqrt{3} - 1), \\
\mu_1 &= 6\,\xi_0\,(2\sqrt{3} - 3), \\
\mu_n &= 6\,\xi_0\,(\sqrt{3} - 2)^{n-1}\,(2\sqrt{3} - 3) \,, \quad n > 1.
\end{aligned}
\qquad (4)
$$

Using the equilibrium equations the nondimensional deflection of the n-th span due to the displacement at point 0 may be expressed with respect to ξ_{n-1}, θ_{n-1}, μ_{n-1} and ρ_{n-1} ; after some algebraic manipulation, we find

$$\xi^N (x) = \left[- \sqrt{3}/6\ x + x^2/2 - \frac{3-\sqrt{3}}{6}\ x^3 \right] \mu_{n-1} . \qquad (5)$$

The deflection in each span has a maximum at

$$x = \frac{1 - (2-\sqrt{3})^{1/2}}{3 - \sqrt{3}}$$

the val e of which is obtained by introducing Eq. (6) and Eq (4_3) in Eq (5). We have

$$|\xi^N_{max}| \approx 0.1367\ \xi_0\ (2-\sqrt{3})^{n-2}$$

which yields in particular

$$\frac{|\xi^3|_{max}}{|\xi_0|} \approx 0.0366 < 5\ \%.$$

The displacement response ratio beyond the second transverse blocking is reduced to a negligible value.

The same evaluation can be done for the support load response ratio, with the same general conclusions.

5. APPLICATIONS

Typical applications of the overlap technique are discussed elsewhere (Ref./10/).

6. CONCLUSION

The heuristic derivation of the overlap technique (filtering of the dynamic influence of downstream piping through a non uniquely located full anchor) is substantiated by the demonstration of the fading of the response ratio in simple beam models.

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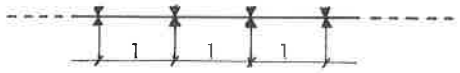

FIGURE 1 : CONTINUOUS BEAM

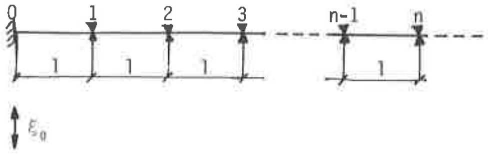

FIGURE 2 : SEMI- INFINITE BEAM