Analysis of Interaction of Cable Trays, Piping, Conduits, and their Supports in a Dynamic Event

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ABSTRACT

A simplified time history analysis method for calculating maximum response of components under floor motion plus impact resulting from inadequate clearance between the components is described. Results for typical components show that for some systems, the interaction effect can be severe and generally an evaluation of interaction effect is desirable. A zero-gap assumption between components is not always conservative; therefore, evaluations should account for sensitivity of response to the value of this parameter.

1. Introduction

Because of in-place construction, the impact of components during a major dynamic excitation of a nuclear power plant cannot always be ruled out. According to the requirements of U.S. NRC Regulatory Guide 1.29, the loss of function of safety-related components caused by impact from non-safety-related components should be prevented. In recent safety evalution discussions, there was also concern about the interaction of safety-related components. To address this problem in practice, a walkdown was performed to prepare Potential Interaction Reports (PIR) and an analysis was made to assess the severity of interaction.

This paper presents a simplified time history analysis method for calculating the interaction effects on components. Results of typical cases of interaction are presented to show the consequence of interaction for some components. The effect of existing gap between the components is also discussed for developing walkdown criteria and for indicating the sensitivity of maximum response to this parameter.

2. Method of Analysis

To consider the interaction of two multimass components $j=1,2$, with a supporting floor motion $x_g(t)$, the following assumptions are adopted (see Figure 1):

2.1 Each component under floor motion plus impact responds in a single governing mode vector denoted by $\underline{\Psi}_j$ for system j.

2.2 The momentum transfer at each impact between the two systems occurs according to particle impact. The equivalent particle for each system is assumed to have a generalized modal mass m_j and the same velocity as that of the point of contact p_j in the actual component j. With these assumptions, it can be verified that the displacement vector of each system j is given by eq. (1).

$$\underline{q}_j (t) = u_j (t, \Delta) \underline{\Psi}_j \tag{1}$$

where $\underline{q}_j(t)$ = component displacement vector and $u_j(t, \Delta)$ = spring distortion of the associated impacting single-degree-of-freedom systems shown in Figure 2 for a preselected gap Δ . Note that for eq. (1) to hold true, mode shapes must be normalized so that the mode shape amplitude at point of contact is unity, i.e.,

$$\underline{\Psi}_j (p_j) = 1.0 \tag{2}$$

In Figure 2, participation factor γ_j for system j is defined in the customary manner using the normalized modes of eq. (2); see Figure 2 for detailed expressions.

To perform an analysis, the equations of motion of single-degree-of-freedom systems in Figure 2 are integrated simultaneously step-by-step, and when an impact occurs, conservation of momentum and elastic impact condition is used to obtain the postimpact velocities as a function of preimpact velocities as follows:

$$\dot{u}_1(t^+) = \dot{u}_1(t^-) - (\frac{r}{1+r})\ [\dot{u}_1(t^-) - \dot{u}_2(t^-)] \qquad (3a)$$

$$\dot{u}_2(t^+) = \dot{u}_2(t^-) - (\frac{1}{1+r})\ [\dot{u}_2(t^-) - \dot{u}_1(t^-)] \qquad (3b)$$

where $\dot{u}_j(t^-), \dot{u}_j(t^+)$ = velocities before and after impact of system j and

$$r = \frac{m_2}{m_1} \qquad (4)$$

with m_j = generalized modal mass of system j.

The following comments are offered in support of the above assumptions:

a) Interaction analysis is performed in the context of single span of conduits, cable trays, or their ceiling-mounted hangers. For floor motion analysis without impact, it is well known that single mode response analysis for these types of components is acceptable. When impact occurs, the system is also subjected to a concentrated impulsive force at the point of impact. Considering specific component designs and higher mode contribution for response under impulsive loads, correction factors can be evaluated to consider the effect of higher modes. This information for three systems of interest is given in Table 1.

b) From eq. (3) and eq. (4) it is seen that momentum transfer between the impacting systems depends on mass ratio r and not on the specific mass values. Therefore, similar assumptions on computation of the participating mass in both systems during the impact process should produce maximum response results which are not too sensitive to a reasonable variation of the mass ratio r. This relative insensitivity has been verified through specific examples.

The application of the time history analysis procedure just described yields the maximum displacement in each component as

$$U_j(\Delta) = \max_t \left| u_j(t,\Delta) \right| \qquad (5)$$

from which the force vector to be applied to the component is determined as

$$\underline{F}_j = \omega_j^2\ U_j \underline{M}_j \underline{\Psi}_j \qquad (6)$$

where ω_j = circular frequency of component and M_j = mass matrix of the component. If force application in combination with other active loads shows inelastic action in the component, and if the component detail can tolerate some inelastic action, an energy balance is used to estimate the maximum ductility demand. The maximum energy input is estimated from

$$E_j = \frac{1}{2}m_j(\omega_j U_j)^2 \qquad (7)$$

This input energy is equated to the strain energy stored in the component. For this latter evaluation, a load deflection diagram for the component is constructed assuming that the limited inelastic deformation in the system occurs when the deformation pattern of the component remains in the governing mode shape $\underline{\Psi}_j$.

For determining U_j in eq. (5), separate analyses are made as the frequency ratio and the mass ratio of the components are each varied within ± 20% to account for sensitivity of response to details of floor motion history $x_g(t)$. The application of the procedure is computationally efficient to permit this parameter variation economically. Also, the applicable values of the modal damping are used in the analysis of component response.

3. Typical Results for Severity of Interaction Response

Results are given for two cases of interaction drawn from actually designed components to show the severity of interaction response compared to the case without interaction. For both cases, gap Δ between components is assumed to be zero. Case 1 involves possible interaction of a cable tray hanger with conduit hangers of various lengths, Figure 3. The cable tray hanger was treated as a multimass system and its interaction with each conduit hanger, A through F, was treated separately. Results of this case for maximum stress in cable tray hanger are summarized in Table 2. The value of design stress given in column 2 of Table 2 is the maximum stress produced in cable tray hanger by floor motion alone. Column 3 lists the ratio of floor motion plus impact to design stress for Cases A through F. Note that the maximum interaction effect is 70% more than the floor motion alone. The ratio of maximum stress to yield stress in column 4 shows that the cable tray hanger in this example remains elastic. Results on conduit hangers (not presented here) showed that they also remain in the elastic range, even when effects from other components of floor motion were considered in the analysis.

Case 2 involves interaction of light and heavy cable tray hangers shown in Figure 4. Controlling responses are the bending moments shown as M_a on each of the two hangers. The heavy hanger was treated as a multimass system. Results in Table 3 show that as a consequence of interaction, the heavy hanger remains elastic. The light hanger, on the other hand, responds inelastically. The extent of inelastic action is, however, limited. The maximum joint ductility demand for this hanger is 1.6.

The results just summarized indicate that interaction response in some cases may be severe and that an analysis should be performed to evaluate the consequences of an interaction.

4. <u>Effect of Gap Between Components</u>

For interaction studies, the effect of gap between components is of interest in two respects. First, gaps often exist between the components. Therefore, it is important to know whether a zero-gap assumption in analysis provides conservative results. Second, for establishing walkdown criteria, a range of permissible gap between components is needed so that components installed with a larger gap can be excluded from consideration. Certain exploratory results are summarized in this section.

Figure 5 summarizes results obtained by subjecting two associated impacting single-degree-of-freedom systems to a specific floor motion history. The mass ratio $r = 0.5$, damping for each component is 10% and the frequency of the lighter System 2 is $f_2 = 4.46$ cps. These parameters have been selected to represent a specific cable tray hanger interaction problem. The gap distance Δ and frequency of System 1 are varied as indicated in the figure. Figure 5a shows the ratio $U_2(\Delta)/U_2(\Delta=0)$ against the gap distance Δ when ratio $f_1/f_2 = 0.57$, 0.86, and 1.29. The denominator of the plotted response ratio is the maximum response when initial gap Δ is zero. Note that as the gap distance increases, the maximum response eventually becomes equal to the maximum floor motion response without impact, herein called U_{20}. This is seen in Figure 5a by the constant portion of the curves. Figure 5a shows that for the systems considered, the zero-gap analysis yielded higher maximum response than that caused by floor motion alone. More significantly, whereas for some systems the zero-gap analysis provides a conservative estimate of maximum interaction response, this is not true for all values of system parameters; for example, when $f_1/f_2=1.29$, the maximum response occurs at $\Delta = 0.2$ inches rather than at $\Delta = 0$. Some parameter optimization appears to be necessary in order to obtain appropriate gap distance for interaction studies. This can be done either by studying a suitable range for considering measurement tolerances, or by including a liberal frequency range variation in frequency parameters and using the zero-gap results.

Figure 5b shows the variation of $U_2(\Delta)$, normalized to the no impact maximum response U_{20}, against the gap distance measured in terms of $U_{10}+U_{20}$. Obviously if $\Delta > U_{10}+U_{20}$, no interaction occurs. Furthermore, Figure 5b shows that no significant interaction occurs for values of $\Delta > 0.7(U_{10}+U_{20})$. These results, when verified by an extensive parameter variation, are of interest for the purpose of developing generic exclusion criteria for walkdown instructions.

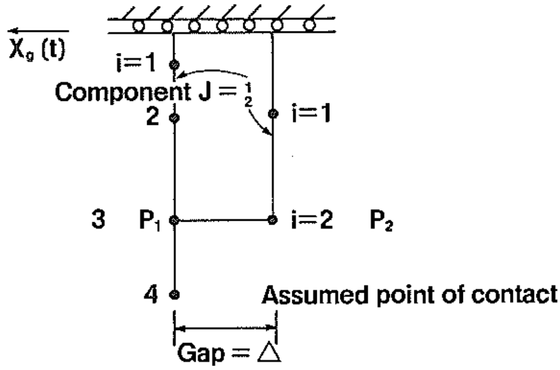
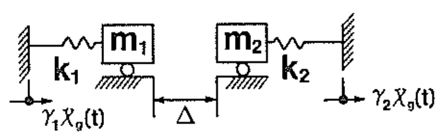


Figure 1 Interacting Components



$$m_j = \Psi_j^T M_j \Psi_j$$

$$k_j = \omega_j^2 m_j, \quad \gamma_j = \frac{\Psi_j^T M_j \mathbf{1}}{m_j}$$

$$\mathbf{1} = [1,1,\ldots 1]^T$$

Figure 2 SDF Systems Associated with Interacting Components

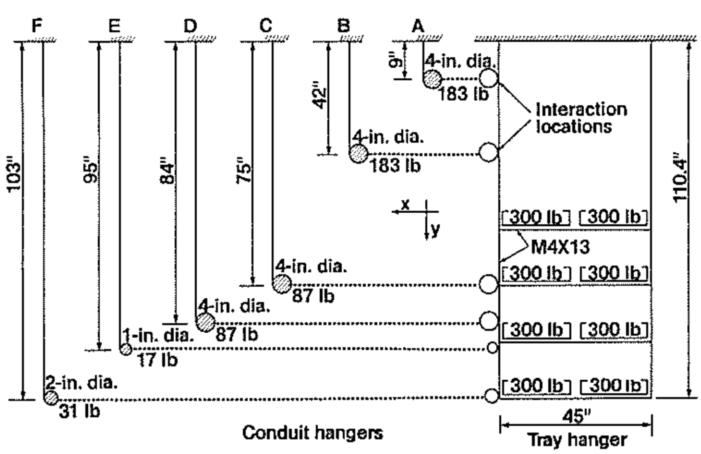


Figure 3 Interaction of Cable Tray Hanger and Conduit Hangers

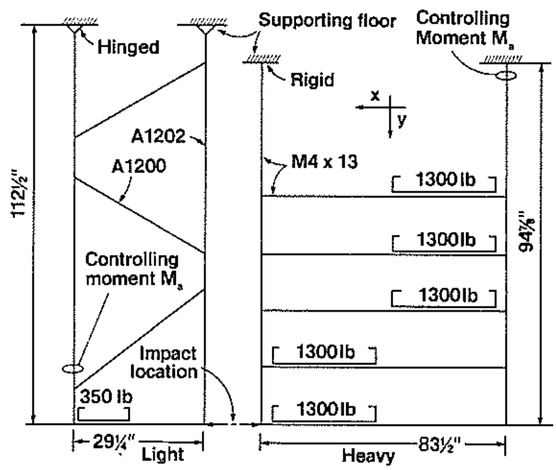


Figure 4 Interaction of Two Cable Tray Hangers

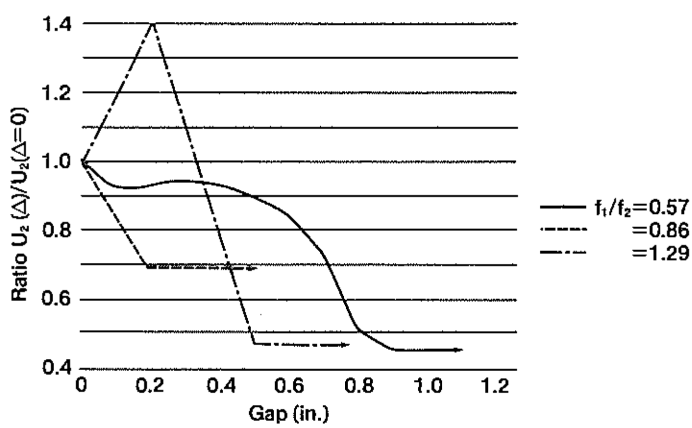


Figure 5 Maximum Response Normalized To Zero - Gap Analysis Values

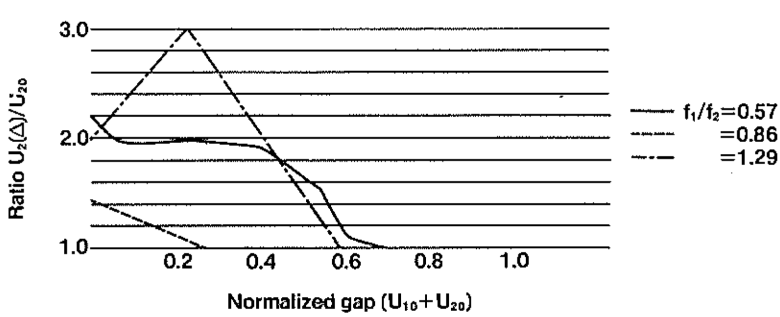
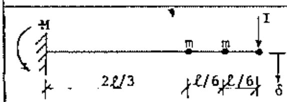
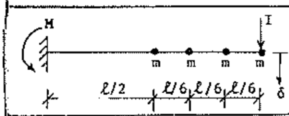
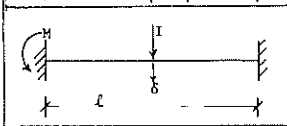


Figure 6 Maximum Normalized Gap Size To Limit Interaction Response To Normalized Values

TABLE I CORRECTION FACTOR FOR HIGHER MODE EFFECT (IMPULSIVE LOADING)

Component	Ratio of Total Response to First Mode Response		
	δ	Moment	SE
	1.03	1.27	1.11
	1.03	1.40	1.16
	1.09	1.46	1.42

SE = Strain Energy
I = Impulse

TABLE II INTERACTION RESPONSE FOR CABLE TRAY HANGER IN FIGURE 3

Impacting System	Design Stress PSI	Interaction Stress / Design Stress	Estimated Stress Ratio = Maximum Total Stress / Yield Stress
A	13,100	1.19	0.45
B	13,100	1.57	0.59
C	13,100	1.56	0.58
D	13,100	1.56	0.58
E	13,100	1.48	0.55
F	13,100	1.70	0.63

TABLE III INTERACTION RESPONSE FOR CABLE TRAY HANGERS IN FIGURE 4

Cable Tray Hanger	Controlling Response	Design Value In-Lb	Value From Interaction Analysis In-Lb	Maximum Total Stress / Yield Stress	Maximum Joint Ductility
H62 Light	Moment M_a	3,640	21,760	1.13	1.6
H54 Heavy	Moment M_a	128,850	177,250	0.94	---