CRITICAL SEISMIC ASSESSMENT OF LIFE-LINE STRUCTURES

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SUMMARY

Life-line structures as the term implies are economically or socially important structures, the damage of which will result in irreparable losses. The assessment procedure employed against seismic events for these structures must be based on higher confidence levels than those employed for regular structures.

This paper presents an upper bound or critical excitation approach for the assessment of the life-line structures. It embodies the principle of critical excitation applied to important structures[1], and the specific characteristic of traveling wave effect on extended structures [2]. The investigation shows that the traveling effect of the seismic wave plays an important role.

CRITICAL EXCITATION

A "critical excitation" is defined as an excitation among a class of "credible" excitations of the same characteristics (site conditions, epicenter distance, etc.) that will produce the largest response peak for a design variable of interest. To produce the critical excitation, the procedure starts with the search and collection of a set of representative ground accelerograms recorded at similar geological sites. These records form the "basis" excitations:

$$x_i(t) \ ; \ i = 1, 2, \ldots, N \tag{1}$$

A potential future ground excitation is posturated as the linear combination of these:

$$X(t) = \sum_{i=1}^{N} a_i \, x_i(t) = \underline{a}^T \, \underline{x} \tag{2}$$

where $\underline{a}$ are the unknown coefficients to be determined so that the response for a desired design variable will be maximized.

The basis excitations as well as the critical excitation must obey the intensity constraint

$$\|x\| \leq E \tag{3}$$

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INTENSITY CONSTRAINT

There are numerous definitions of earthquake intensity $||X||$: peak acceleration is one, spectral density is another. In this paper the square integral of the excitation spanning the "effective" duration t_e is used as the intensity measure:

$$||X|| = \sqrt{\int_0^{t_e} X^2(t)dt} \tag{4}$$

The "effective" duration of an excitation depends on the fundamental period and damping of the structure and has been discussed elsewhere [3]. For ratios of critical damping in the range of 0.02 to 0.05, the effective duration may be taken as equal to four to eight times of the fundamental period. The reference intensity E in Eq. 3 depends on the seismic zoning and importance of the structure. By combining Eqs. 2, 3 and 4 one obtains

$$E^2 \geq \sum_{i=1}^{N} \sum_{j=1}^{N} a_i a_i \int_0^{t_e} x_i(t)\, x_j(t)dt$$

or

$$E^2 \geq \underline{a}^T \cdot G \cdot \underline{a} \tag{5}$$

where G is a N x N matrix with the typical element

$$G_{ij} = \int_0^{t_e} x_i(t)\, x_j(t)dt \tag{6}$$

CRITICAL RESPONSE

The response of a linear system to an excitation X(t) is

$$y(t) = X(t) * h(t) \tag{7}$$

where the symbol $*$ stands for convolution and h(t) is the unit impulse response of the oscillator. Eq. 7 can be written as

$$y(t) = \left[\sum_{i=1}^{N} a_i x_i(t)\right] * h(t) = \sum_{i=1}^{N} a_i y_i(t)$$

or in matrix form:

$$y(t) = \underline{a}^T \cdot \underline{y} \tag{8}$$

where $\underline{y}$ is a N-vector of individual responses due to basis excitations $\underline{x}$. From the above, the determination of the critical excitation $x^c(t)$, or the vector $\underline{a}$, is expressed mathematically as:

$$\begin{cases} |\underline{a}^T \cdot \underline{y}| = \max & \forall \; \underline{a}, t \\ \text{subject to constraint} & \\ \underline{a}^T \cdot G \cdot \underline{a} \leq E^2 & \end{cases} \tag{9}$$

this is a double maximization under a constraint. The maximization with respect to $\underline{a}$ is carried out by linear algebra while that with respect to t by using a numerical evaluation [1]. Employing the Lagrangian multiplier λ the maximization of Eq. 9 with respect to $\underline{a}$ leads to

$$\underline{a} = -\frac{1}{2\lambda} \underline{y} \tag{10}$$

and the equal constraint of Eq. 5 leads to

$$\lambda = \frac{1}{2E} \left[\underline{y}^T G \underline{y} \right]^{\frac{1}{2}} \tag{11}$$

TRAVELLING WAVE EFFECT

When the spatial dimension of a structure is great in comparison with the traveling wave velocity, incident ground motions acting on the discretitized points of the life-line structure cannot be considered to occur at the same instant. In this investigation the phase differences or time lags of these incident excitations were considered to be proportional to $\ell/_c$ where ℓ is the distance between the two points in consideration and c is the shear wave velocity. Thus, the unit impulse response h(t) in Eq. 7 is the result of superposition of the responses for a given design variable due to unit impulses applied at the m discrete points with time lags τ_k.

$$h(t) = \sum_{k=1}^{m} h_k \, (t + \tau_k) \tag{12}$$

where τ_k is equal to $\ell_k/_c$.

APPLICATION OF THE METHOD

In order to demonstrate the concept of the critical assessment of life-line structures, a buried pipeline system was selected. The response of such structures subjected to ground motion is of major importance as pointed out in reference [4]. A three dimensional model shown in Fig. 1 was used. The soil effects were modeled by soil springs attached at the discrete nodal points in two transverse directions. The soil spring k_{v1}, ... k_{vm} represent soil effects in the vertical direction while k_{h1}, ... k_{hm}, in the horizontal direction.

The above idealized soil-structure system was subjected to an axially traveling ground excitation while the responses considered were those in the transverse directions. Twenty ground accelerations recorded in California at stiff soil site conditions were selected as basis. The maximum intensity E was taken to be equal to that of the El Centro 1940 N-S component. The time-history and the frequency content of this earthquake are shown in Fig. 2. Critical excitation by using these twenty basis excitations traveling along the axis of the pipe were produced using the above mentioned method for the representative displacements, moments and shears. The time-history and frequency content of a typical critical excitation is shown in Fig. 3. By comparison of Fig. 2 and Fig. 3 it appears that the critical excitation is a realistic candidate of possible future ground acceleration at such a site.

To further study the traveling or time-lag effect of excitation along the axis of the pipe line, two cases were investigated. The first one assumes that the excitations were applied simultaneously at all the nodal points, while the second one considers the time lags of the nodal points. The results of the representative responses are shown in Fig. 4. It can be concluded that the traveling effect of the excitation on life-line structures appears to be significant.

In conclusion, from this preliminary study, the critical excitation approach including the traveling wave effect can be utilized to enhance the confidence level for the design of life-line structures.

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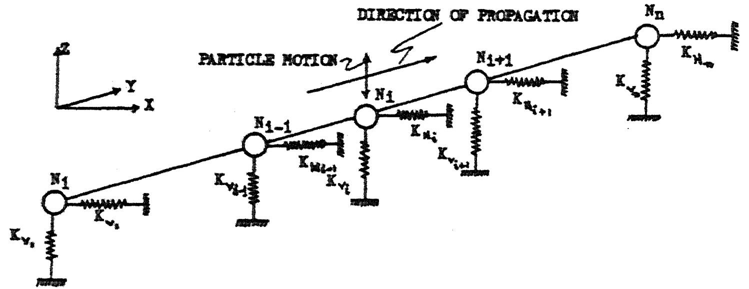

FIG. 1. SOIL/STRUCTURE MODEL.

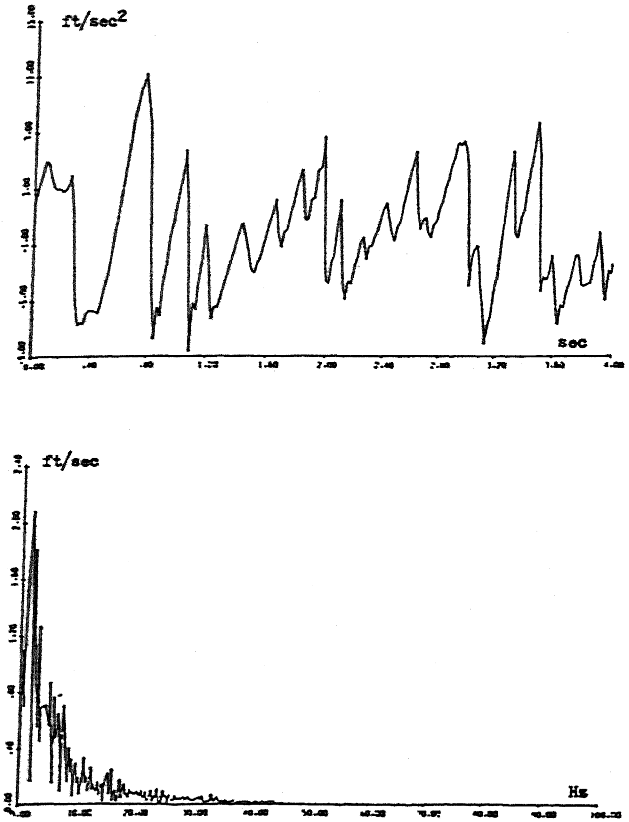

FIG. 2. EL CENTRO 1940 EARTHQUAKE.

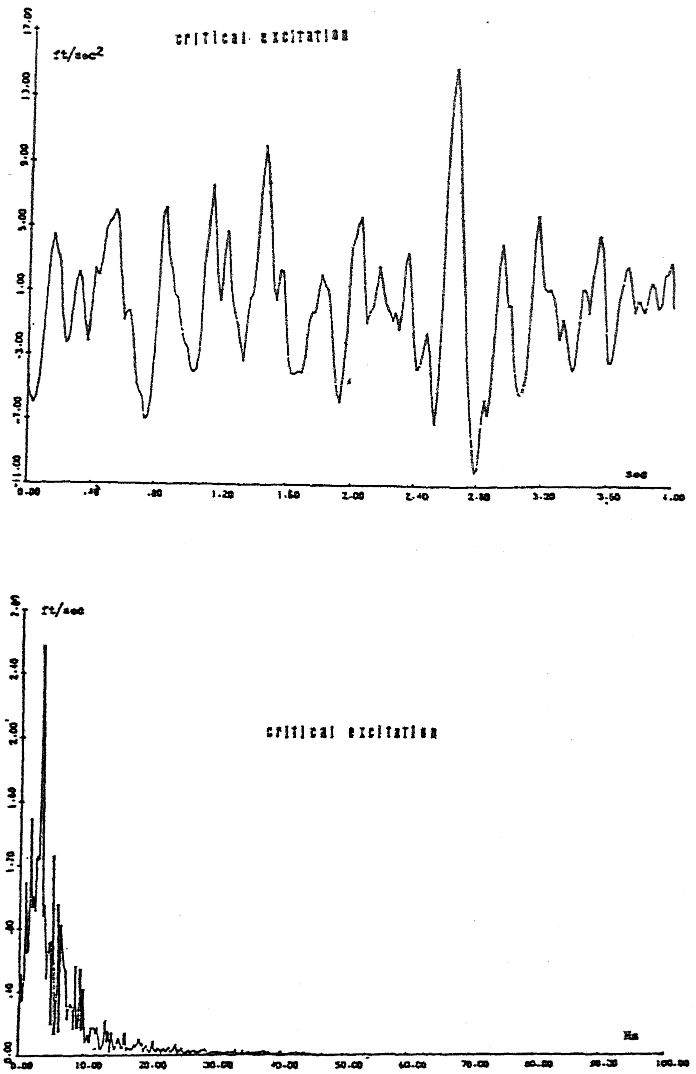

FIG. 3. TIME HISTORY & FREQUENCY CONTENT OF TYPICAL CRITICAL EXCITATION.

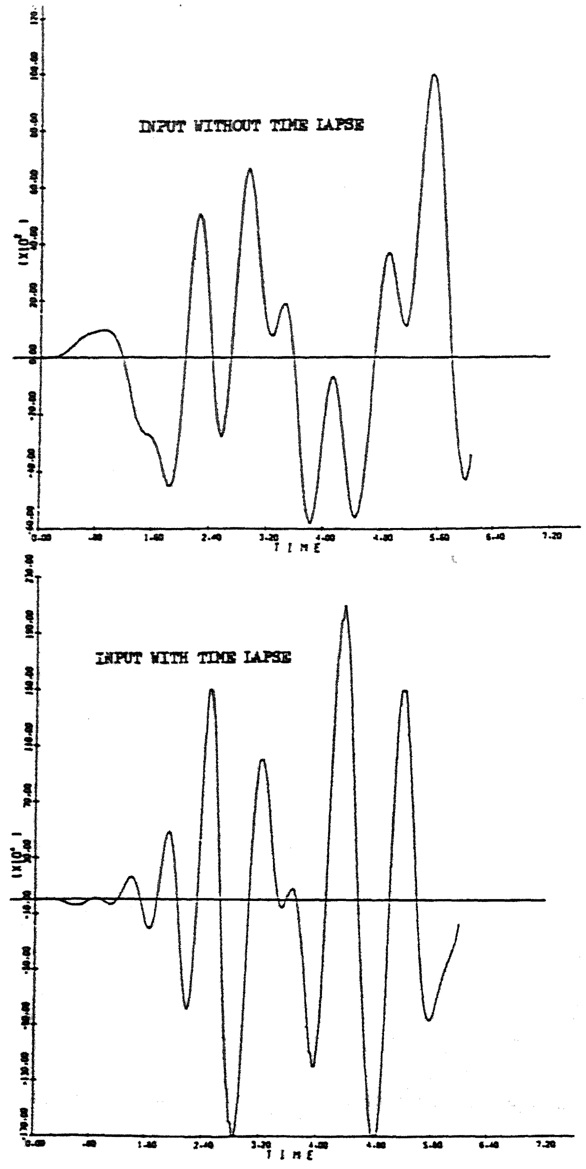

FIG. 4. COMPARISON : TYPICAL PEAK RESPONSE TIME HISTORIES.