PARABOLIC LATERAL LOADS FOR EARTHQUAKE RESISTANT STRUCTURES

by

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SYNOPSIS

Different types of structures including frames, shear walls, box systems, chimneys, towers, masts, etc., were simulated by means of a mathematical model, and subjected to a rigurous dynamic analysis using a digital computer. Quasi-static loads were then evaluated in such a way that when applied to the model they would produce an equivalent dynamic response of the structure. The effects of parameters such as earthquake magnitude, rigidity of the structure, shear-flexural ratio, stiffness and mass distribution, and number of stories, upon the responses of the structure, were analyzed independently. From the data obtained a method of predicting a set of design quasi-static lateral loads that would yield responses greater than or equal to those given by a complete modal analysis was developed. The recommended method is presented, illustrated by an example, and compared to several current seismic codes.

THE METHOD

The loading system given by this method consists of a base reaction which is distributed as a set of concentrated lateral forces applied on the structure. A parabolic variation of such loads was found to produce structural responses that are very similar to the actual dynamic responses, with correlations of 0.99 or higher (1). Additional concentrated loads at the first and top stories are included to account for the so called end effects or "whip action", as shown in Fig. 1. The first step in this method (2) is calculating a base reaction according to the following equation

$$R = CBR \cdot CBT \cdot CBK \cdot CBN \cdot BM \cdot W \cdot \frac{f}{0.075}$$

where, W is the total weight of the structure, f is the fundamental frequency in cps. (obtained from any of the formulas available in the literature (3)), BM is a base magnitude given by the standard spectrum shown in Fig. 2, CBR, CBT, CBK, and CBN are scaling factors to account for earthquake magnitude, type of structure, stiffness distribution, and number of stories, respectively, and given by the equations shown in Table 1. The base reaction is then distributed along the height of the structure proportionally to the following coefficients for each story:

$$VD_i = 0.1\, A_0' + A_1' \,(h_i/h_n) + A_2' \,(h_i/h_n)^2$$

where, VD_i is the vertical distribution coefficient for story i, h_i and h_n are the heights of story i and the top story over the base; A_0', A_1', and A_2' are the parabolic coefficients determined as follows

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$$A' = A\left[(CDT + CDK + DT + DK - 1) \pm (CDN + DN - 1)\right]$$

where, CDT, CDK, and CDN are scaling coefficients for type of structure, stiffness distribution, and number of stories, respectively; DT, DK, and DN are the corresponding scaling increments calculated by the expressions shown in Table 1. A'and A take the appropriate 0, 1 or 2 subscripts. The + sign is used when $(CDT + CDK + DT + DK - 1) < 0$; the - sign is used in the oposite case. The values of A_0, A_1, and A_2 are given in Fig. 3. The end loads are obtained from the following equation

$$F_k = EL_k \cdot R \qquad (k = 1 \text{ or } n)$$

where the coefficients EL_k are given in Table 1. Finally, the quasi-static lateral design load at story i is calculated as follows

$$P_i = (R - F_1 - F_n)\, VD_i \Big/ \sum_{i=1}^{N} VD_i$$

To illustrate the method, a 16-story building was subjected to the process indicated above (4). The resulting quasi-static lateral loads are shown in Fig. 5 (curve labeled "Estrada"). The figure also shows the corresponding loads calculated by means of several other methods currently used in seismic codes (5). The "exact" curve obtained from a modal analysis would be almost on top of the one given by the method discussed here.

CONCLUSIONS

A method of predicting a set of quasi-static lateral loads for designing earthquake resistant structures was presented. The loads have a parabolic variation that gives structural responses very similar to the actual dynamic responses. The results obtained by this method are comparable to those given by several current seismic codes. The linear distribution of lateral loads given by some codes may be considered as a particular case of the more general distribution proposed here. The method may be included in code provisions (6), and programmed for computer solution.

REFERENCES

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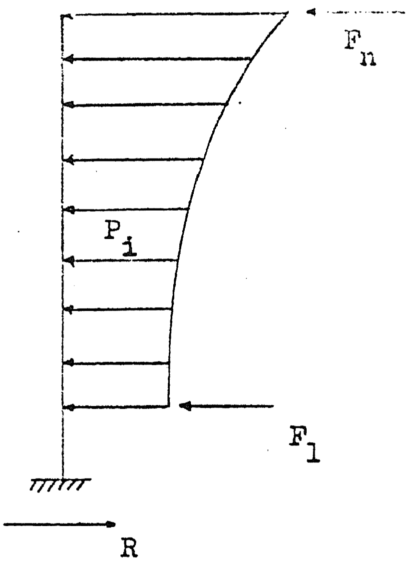

Fig. 1 - Loading system

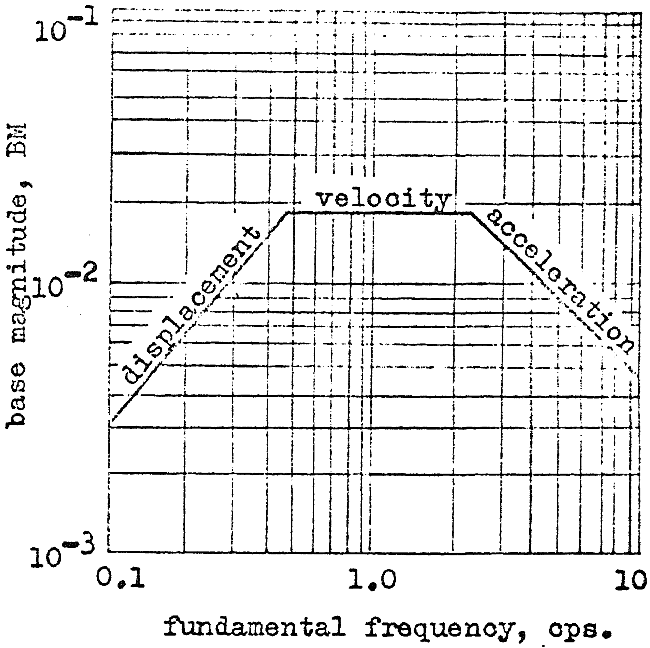

Fig. 2 - Standard spectrum

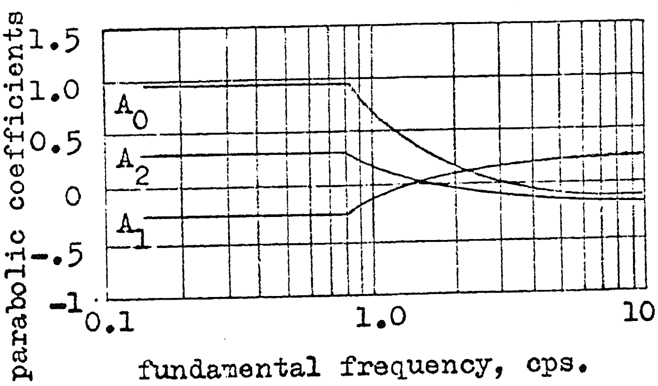

Fig. 3 - Parabolic coefficients

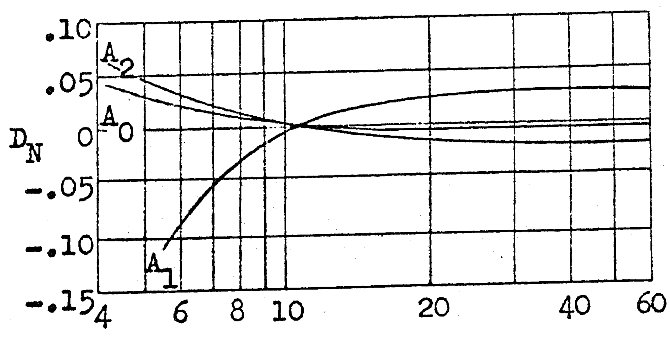

Fig. 4 - Scaling coefficients for number of stories

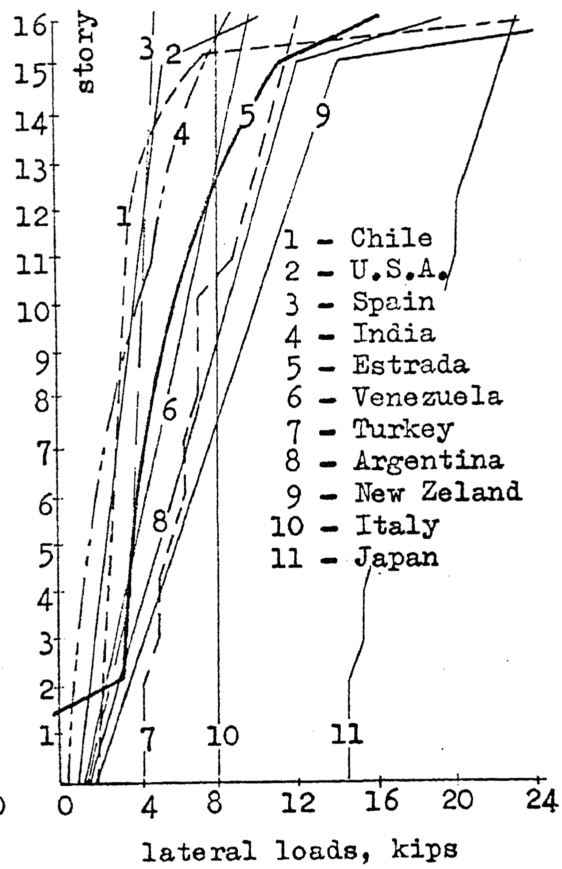

Fig. 5 - Comparison of loads for a 16-story building

TABLE 1

SCALING COEFFICIENTS

Expression	Comments
$CBR = \log^{-1}\left(\frac{MR - 7.4}{2.0}\right)$	MR = earthquake magnitude (Richter)
$CBT = 1.0 \qquad r_t > 1$	$r_t = K_{b1}/K_{c1}$ (shear-flexural ratio) where, K_{b1} and K_{c1} are the total stiffnesses of the beams and columns in the first floor.
$CBT = \log^{-1}\left(\frac{1 - P_t}{Q_t}\right) \qquad r_t < 1$	
$P_t = \log^{-1}\left(\frac{a_t - r_t}{b_t}\right)$	a_t, b_t, d_t, and e_t are given in Table 2.
$Q_t = \log^{-1}\left(\frac{r_t - d_t}{e_t}\right)$	$r_k = K_{cn}/K_{c1}$ (stiffness distribution ratio) where, K_{cn} and K_{c1} are the total column stiffnesses in the top and first stories.
$CBK = r_k^{-0.252}$	
$CBN = \log^{-1}\left(\frac{1 - \log N}{1.1}\right)$	N = number of stories.
$CDT = 1.35$	
$DT = a'_t \log^{-1}\left(d'_t + \frac{r_t - e'_t}{b'_t}\right)$	a'_t, b'_t, d'_t, and e'_t are given in Table 2.
$CDK = r_k^{0.058}$	
$DK = [a_k + b_k(\log r_k - d_k)]\, e_k$	a_k, b_k, d_k, and e_k are given in Table 2.
$CDN = \log^{-1}\left(\frac{1 - \log N}{b_n}\right)$	b_n is given in Table 2.
DN is given in Fig. 4	
$EL_1 = -0.04\, A'_0$	
$EL_n = 0.05\, A'_2 - 0.001$	

TABLE 2

PARAMETERS FOR SCALING COEFFICIENTS

Parameter	A_0		A_1		A_2	
	$r_t > 0.33$	$r_t < 0.33$	$r_t > 0.33$	$r_t < 0.33$	$r_t > 0.33$	$r_t < 0.33$
a_t	0.73	0.54				
b_t	4.15	2.21				
d_t	-0.33	0.06				
e_t	1.41	0.58				
a'_t	1.00	1.00	-1.00	-1.00	1.00	1.00
b'_t	-3.00	-3.00	-3.95	-1.69	-3.25	-1.33
d'_t	-0.54	-0.54	-0.56	-0.39	-0.61	-0.40
e'_t	1.00	1.00	1.00	0.33	1.00	0.33
	$r_k > 0.20$	$r_k < 0.20$	$r_k > 0.20$	$r_k < 0.20$	$r_k > 0.20$	$r_k < 0.20$
a_k	0	0.0825	0	-0.0980	0	0.1390
b_k	-0.0860	-0.0388	0.1080	0.0380	-0.1660	-0.0400
d_k	0	-1.28	0	-1.28	0	-1.28
e_k	1.00	1.00	-1.00	-1.00	1.00	1.00
b_n	0.3540	0.3540	0.80	0.80	0.51	0.51