RECOMMENDATIONS FOR SEISMIC ANALYSIS
OF BURIED PIPE LINES IN MEXICO CITY

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SUMMARY

This paper presents a simple procedure to carry on the seismic analysis of lock-joint concrete buried-segmented pipe lines, to be constructed in Mexico City. Such procedure is based on a joint-friccionant model whose formulation is given in Ref 1, including various parametric analysis. This study, conjunctly with a statistical analysis of existent seismological information in the Federal District, leads to the practical recom-- mendations presented in this paper. Pipe lines placed in Mexico City's soft and hard soil zones are considered and the return period of the design earthquake can also be managed explicitely.

INTRODUCTION

Earthquakes have caused a great number of damage in water pipe lines in several sites of the world (Ref 2). Because of the social, political and public health importance that such failures have, it is necessary to reduce the corresponding risk. This method is based on a model developed by the authors in Ref 1, called joints frictionant model, because the - restriction to movement in pipe joints is modeled by friction forces. - Particular application to Mexico City Soils and Seismicity, and parametric analysis, lead to the recommendations given in this paper.

ANALYSIS PROCEDURE

The analysis procedure recommended here, is the following:

1. Choose the return period, T, of the design earthquake. For aqueducts it is advisable to take at least 100 years.

2. Calculate the expected value of the maximum horizontal ground aceleration and velocity, $\tilde{A}_{max}$(cm/seg^2) and $\tilde{V}_{max}$(cm/seg), respectively. From - statistical analysis (Ref 3) these are obtained with the following equations, in which T is given in years.

For soft soil, if $T \geq 2$ years:

$$\tilde{A}_{max} = 25.4T^{0.37} \quad \text{and} \quad \tilde{V}_{max} = 7.6T^{0.37} \tag{1}$$

For hard soil, if $T \geq 2.5$ years:

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$$\tilde{A}_{max} = 16.2\ T^{0.37} \quad \text{and} \quad \tilde{V}_{max} = 4.4\ T^{0.37} \qquad (2)$$

3. Determine the shear wave propagations velocity in the underlying soil, on which the pipe line will be placed. For this purpose, a conservative value of such velocity can be obtained with the equation

$$v'_s = \sqrt{G/\rho} \qquad (3)$$

where ρ is the soil density and G is the soil shear modulus obtained by means of a static test.

Some indicative values are the following (Refs 3,4 :

v'_s = 35 m/seg, in highly soft soil, like in the Texcoco Lake and - Mexico City's downtown

v'_s = 170 m/seg, in soft soil, like the Xochimilco's lacustrine zone

v'_s = 400 m/seg, in fairly hard soil

v'_s = 700 m/seg, in hard soil or fragmentary rock

4. Calculate the apparent propagation velocity in horizontal direction, v_s:

$$v_s = v'_s\ /\ 0.7 \qquad (4)$$

5. Determine the subgrade reaction modulus, K_v, of the refilling soil of trench on which the pipe line will be lodged. For this, a sample of such material that have the specified compactation degree should be produced in laboratory and a plate standard test should be made to it; the compacta-- tion must be the minimum permited by the others loads to be considered in design.

6. Calculate the stiffness per unit length, K_s, of the refilling soil by means of

$$K_s = \pi D K_v \qquad (5)$$

where D is the outer pipe diameter.

7. Compute the expected value of the maximum relative displacement, - $\tilde{d}_T$, that joints will have in the axial direction:

$$\tilde{d}_T = \{\tilde{V}_{max}/v_s + (\tilde{A}_{max}/v_s^2)(D/2)\}L f_o \qquad (6)$$

where

L pipe segment length

f_o corrective factor for pipe-soil interaction effect

The value of f_o is computed with corresponding formula, between following: for soft soil:

$$f_o = 1.0 - 0.31\rho \quad \text{if} \quad \rho \leq 1.1, \text{ and} \tag{7}$$

$$f_o = 0.87 - 0.19\rho \quad \text{if} \quad \rho > 1.1 \tag{8}$$

and for hard soil:

$$f_o = 0.98 - 0.22\rho \tag{9}$$

where ρ is the stiffness ratio, given by

$$\rho = (LK_s/4)/K_T \tag{10}$$

and K_T is extensional stiffness for each pipe segment.

8. If some pipe segment has a fixed end, the joint of the other end will have a relative displacement, d_T', of magnitude

$$d_T' = \{0.9 + 0.6\, e^{-2\rho}\}\tilde{d}_T \tag{11}$$

9. To avoid collision between two consecutive pipes, a joint opening - equal or greater than $\tilde{d}_T$ or d_T' should be considered. A similar gap - should be used in the interior side, to avoid dislocation when tension effect is present.

10. Calculate the expected value of the pipe strain, $\tilde{\varepsilon}_{60}$, that design -- earthquake would cause to a pipe with 488cm (16ft), 152.4cm (60in) and 179.4(70.6in), of length, internal and external diameter (reference dimensions), respectively, and which is lodged in a trench whose refilling material has a stiffness per unit length, $K_{S'}$, the value of which is calculated by eq (5) with D=179.4 cm. To obtain such a strain, it is necessary to scale the envelopes showed in Fig 1, by multiplying them by a - scaling factor which is $\tilde{A}_{max}/54.9$ on soft soil, and $\tilde{V}_{max}/1.9$ on hard soil. As a particular case, for T = 100 years the design curves are given by:

For soft soil (fig 1): $\tilde{\varepsilon}_{60} = 24.25 \times 10^{-5} K_{s'}^{0.62}$, if $K_{s'} \leq 0.8$ ton/cm/cm, (12)

and

$$\tilde{\varepsilon}_{60} = 25.76 \times 10^{-5} K_{s'}^{0.91}, \quad \text{otherwise} \tag{13}$$

For hard soil (fig 1): $\tilde{\varepsilon}_{60} = 8.46 \times 10^{-5} K_{s'}^{0.21}$, if $K_{s'} \leq 6.0$ ton/cm/cm (14)

and

$$\tilde{\varepsilon}_{60} = 5.84 \times 10^{-5} K_{s'}^{0.42}, \quad \text{otherwise} \tag{15}$$

11. Compute the expected value of the axial strain, $\tilde{\varepsilon}$, for pipe on interest, with following formula

$$\tilde{\varepsilon} = \{\tilde{\varepsilon}_{60}/(D/D_{60})\}f_1 \tag{16}$$

where D(cm) is the external diameter of the pipe on interest, D_{60} is taken as 179.4cm, and f_1 is a corrective factor by pipe length effect.

The f_1 value is calculated with one of the next expressions, where - L_2(cm) is the length of the pipe on interest.

For <u>soft soil</u>: $f_1=\{1.5(488/L_2)\ -0.5\}^{-1}$, if $0.67\leq 488/L_2\leq 1$, and (17)

$$f_1=\{1.84(488/L_2) - 0.84\}^{-1}, \text{ if } 1<488/L_2 \tag{18}$$

For <u>hard soil</u>: $f_1\{1.26(488/L_2)-0.26\}^{-1}$, if $0.67\leq 488/L_2\leq 1$, and (19)

$$f_1 = 1, \quad \text{if} \quad 488/L_2 > 1 \tag{20}$$

12. Calculate the pipe stiffness, K_{T_2}(kg/cm), as it might have 488 cm of length. If this stiffness is different to

$$K_{T_1} = 0.163(D')^2 \tag{21}$$

where D'(cm) is the inside diameter of the pipe on interest, then the $\tilde{\varepsilon}$ value must be multiplied by factor

$$f_2 = K_{T_1}/K_{T_2} \tag{22}$$

13. If the shear wave propagation velocity in horizontal direction, v_s - (cm/seg), is different to 35 m/seg, for soft soil case, or to 410 m/seg, for hard soil, it is necessary to meet the ratios $\varepsilon_{35}/\varepsilon_{v_s}$ or $\varepsilon_{410}/\varepsilon_{v_s}$, - which are in terms of $v_s/35$ or $v_s/410$, and of velocity in the refilling soil, v_{s_R}. Such relations are determined through the Figs 2 or 3 for soft or hard soil, respectively; once that we have the value of this ratio, it is necessary to divide $\tilde{\varepsilon}$ by such value. The velocity v_{s_R}, can be computed by

$$v_{s_R} = 6\ K_{s'}^{0.5} \tag{23}$$

14. If some pipe segment had a fixed end, the strain of such pipe will be:

$$\varepsilon' = \frac{\{2\rho(\tilde{V}_{max}/v_s)L + (\mu p/K_T)\}\ (1 + 0.5\rho)}{\{0.5\rho(\tilde{V}_{max}/v_s)L + (\mu p/K_T)\}\ (1 + 2\rho)}\ \tilde{\varepsilon} \tag{24}$$

where μ if the friction coefficient between rubber gasket and pipe, and p is the force between them.

15. Calculate the axial stress in pipe line, corresponding to strain above computed, as well as tangential stress due the Poisson effect. For design purposes these must be added, according to AWWA specifications, to those caused by other acting loads over pipeline.

16. Finally, compute the rotation capacity, $\tilde{\theta}$, joints must have, by -

means of equation

$$\tilde{\theta} = L\tilde{A}_{max}/v_s^2 \qquad (25)$$

It is important to remark that to apply the procedure described in this paper, it is required that opening joints must not be refilled with morter or some rigid material, but it can be refilled, for example, with pastes which do not become rigid through the years; on the contrary, if left without refilling, the openings must be covered circunferentialy with a plastic tape to avoid penetration of soil.

REFERENCE

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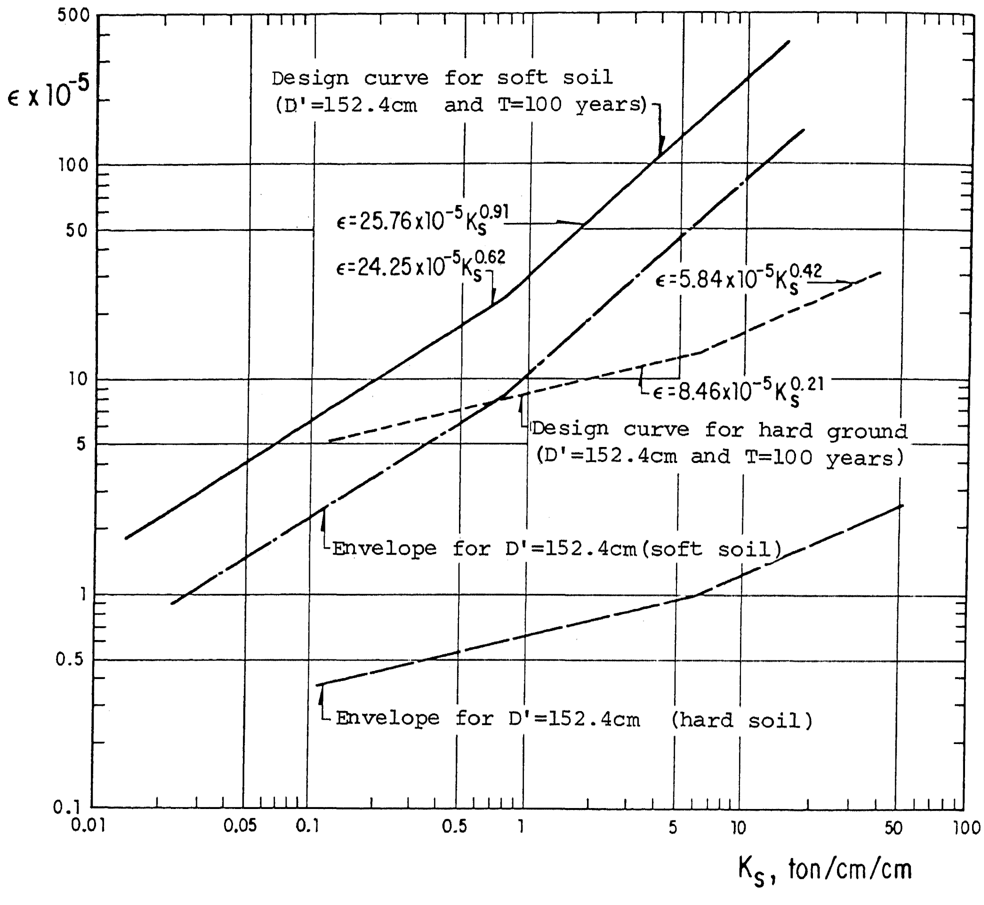

Fig 1. DESIGN CURVES FOR UNITARY STRAINS (T=100 YEARS)

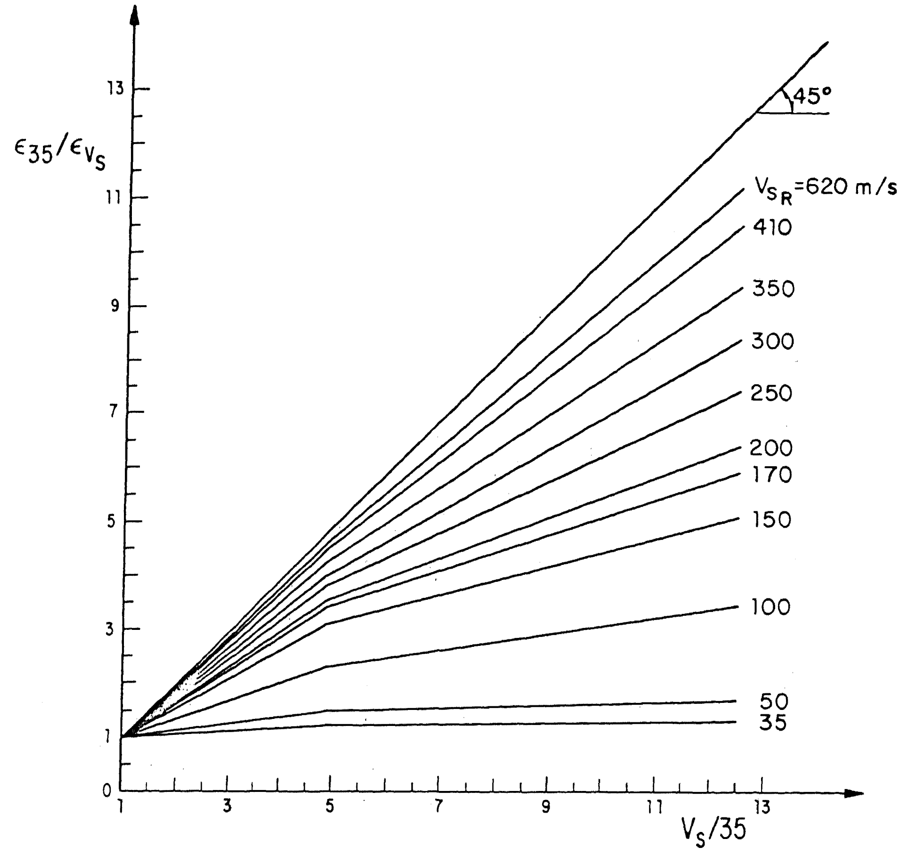

Fig 2. UNIT STRAINS VARIATIONS WITH APPARENT PROPAGATION VELOCITY. SOFT SOIL

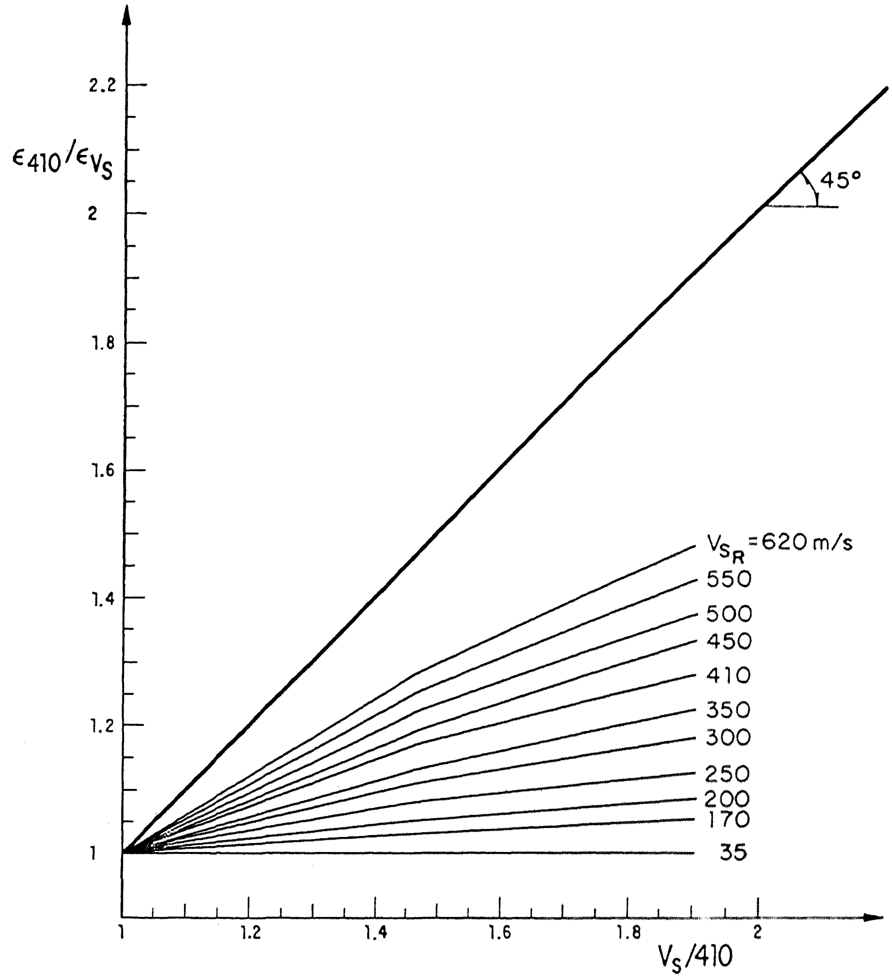

Fig 3. UNIT STRAINS VARIATIONS WITH APPARENT PROPAGATION VELOCITY. HARD SOIL.