Seismic Vulnerability, Behavior and Design of Underground Piping System

Discussion on Soil Restraint Against Horizontal Motion of Pipes

by

Leon Ru-Liang Wang

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Department of Civil Engineering
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7. Author(s)
L.R.-L. Wang

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A systematic way of assessing the adequacy and vulnerability of water/sewer distribution systems subjected to seismic loads and future design methodologies are developed. This technical memorandum comments on the comprehensive report issued in October 1977 by J. Audibert and K. Nyman on the current state of knowledge of soil resistance to horizontal pipe motion, known as the soil subgrade reaction. It is pointed out that these authors treated buried pipes with discrete springs for the analysis of the soil-structure interactions problems. The discussion in this memorandum supplements the report in two respects. Firstly, this discussion stresses the usage of continuous soil springs in the analysis. For buried piping systems which may involve many nodes and members, discrete springs are not considered to be able to model soil resistance properly for given member and rotations. Secondly, from an analysis of existing literature, correlations of the soil horizontal resistance to several other basic soil parameters, other than the ultimate strength used in the report, are made.

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This is the first in a series of Technical Memoranda under the general title of 'Seismic Vulnerability, Behavior and Design of Underground Piping Systems' (SVBDUPS). A technical memorandum is written with somewhat limited objectives and scope as compared to a technical report.

The research has been sponsored by the Earthquake Engineering Program of NSF-RANN under grant No. ENV76-14884 and Dr. S.C. Liu is the Program Manager of this Project in which Dr. Leon Ru-Liang Wang is the Principal Investigator. The overall aims of this research are to develop a systematic way of assessing the adequacy and vulnerability of water/sewer distribution systems subjected to seismic loads and to develop future design methodologies.

The technical memorandum is converted from the discussion paper submitted to ASCE for consideration of possible publication. The author wishes to express his appreciation for the inputs and discussions from Dr. Michael O'Rourke, Senior Investigator and Prof. Dimitrios Grivas, Faculty Consultant of the project and Dr. Jean M.E. Audibert, one of the authors of the original paper.

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Soil Restraint Against Horizontal Motion of Pipes[a]

Discussion by Leon Ru-Liang Wang[1], M. ASCE

The authors have produced a rather comprehensive report on the current state of knowledge of soil resistance to horizontal pipe motion, k_h (Force / unit area/ unit displacement), known as the soil subgrade reaction. In addition to the extensive literature on the soil-pipe and soil-pile interaction problems, the authors present experimental data from in-situ and model tests. These data are valuable in the sense that more data are added to the present vast but uncorrelated data pool. To be useful for the future applications, k_h must be correlated to one or more easily measured parameters. The attempt by the authors to relate the soil restraints to its ultimate values is a step in the right direction. For the analysis of the soil-structure interactions problem, the authors treated the buried pipes with discrete springs.

Note that the soil subgrade reaction, k_h, is not only a very convenient and useful quantity in expressing the soil restraint against horizontal pipe motion, but a very fundamental parameter governing the soil-pipe interaction behavior. However, as indicated by the authors, the definition of soil restraint at the present time is not unique in the literature and the available methods of obtaining adequate values are very imprecise and poorly understood. More investigation and discussion about the subject is needed.

Based on a couple of recent studies[k,ℓ], this discussion supplements the paper in two respects. Firstly, this discussion stresses the usage of continuous soil springs in the analysis. For buried piping systems which may involve many

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(a) October 1977 by Jean M.E. Audibert and Kenneth J. Nyman (Journ. of Geotechnical Engineering Division, Vol. 103, No. GT10)

(1) Associate Professor of Civil Engineering, Rensselaer Polytechnic Institute, Troy, New York

nodes and members, discrete springs can not model soil resistance properly for given member end rotations. To solve the system by a computer it would be appropriate to model the continuous soil resistance by the consistent spring (finite element) approach[k] at the pipe nodes. Basically, by equating the strain energy from the soil continum to that from a set of equivalent nodal displacements governing the buried pipe deflections, the soil resistance stiffness, which is conformable to the pipe element stiffness, can be obtained. Without details, the soil stiffness matrix which represents the horizontal soil resistance within a buried pipe element is given below:

$$[K]_s = \begin{bmatrix} \frac{13}{35} k_L L & & & \text{Symmetric} \\ \frac{11}{210} k_L L^2 & \frac{k_L L^3}{105} & & \\ \frac{9}{70} k_L L & \frac{13}{420} k_L L^2 & \frac{13}{35} k_L L & \\ -\frac{13}{420} k_L L^2 & \frac{-k_L L^3}{140} & -\frac{11}{210} k_L L^2 & \frac{k_L L^3}{105} \end{bmatrix} \quad \text{(a)}$$

Where k_L (Force/unit length/unit displacement) is soil lateral spring constant and L is the length of pipe element.

Note that this matrix, after post-multiplying the nodal deflections and rotations, will yield the equivalent soil resistance components (in terms of forces and moments) at the ends of a buried pipe element which is being deformed consistently to the displacement of the soil continum along the pipe element. The advantage to handle a buried piping system by combining the soil stiffness matrix to the pipe stiffness, which in turn, reduces to an ordinary structural analysis problem, is then obvious.

Secondly, from an analysis of existing literatures[ℓ], the writer wishes to supplement correlations of the soil horizontal resistance to several other basic soil parameters other than the ultimate strength used by the authors.

Theoretically, Parmelee and Ludtke[h] in a recent paper have derived a lateral soil spring constant, k_L using an elastic half space approach as follows:

$$k_L = \gamma E_s \tag{b}$$

in which γ is a dimensionless parameter depending on the ratio of the buried depth to the pipe diameter and E_s is Young's modulus of the soil.

Experimentally, there are data from several investigations not reported by the authors. In 1964, McClure et al[d] reported some experimental data of soil spring constant, k_L, termed as foundation modulus, and soil shear wave velocity, V_s, for several types of soil. The correlation between the soil lateral spring k_L and the soil shear wave velocity, V_s is shown in Fig. a. From this figure, there appears to be a linear relationship between k_L and V_s in a log-log scale.

Recently, Howard[a,b] reported more semi-empirical data of modulus of soil reaction, E' (Force/unit length/unit displacement) for which the traditional culvert design is based[71 to 74]. Although several investigators[1,60] have claimed that E' is not a fundamental soil property, no attempt has been made to correlate E' with other soil resistance parameters such as k_L or k_h.

In Japan, many studies[e,f,g,i,j] have investigated the soil-structure interaction behavior through observations of dynamic responses of underground structures, mostly submerged tunnels. Very recently, Kunihiro et al[c] reported a direct measurement of k_h values at a number of the depths below ground surface using a special tester in boring holes. The corresponding Young's modulus, E_s, at the same depth was obtained by uniaxial compression tests. The correlation between k_h and E_s is shown in Fig. b which also seems to show a linear relationship, but in an ordinary scale.

Finally, despite the fact that there are vast information on the soil-pipe interaction problems mentioned, more research is needed to define and correlate various parameters now in use for practical applications.

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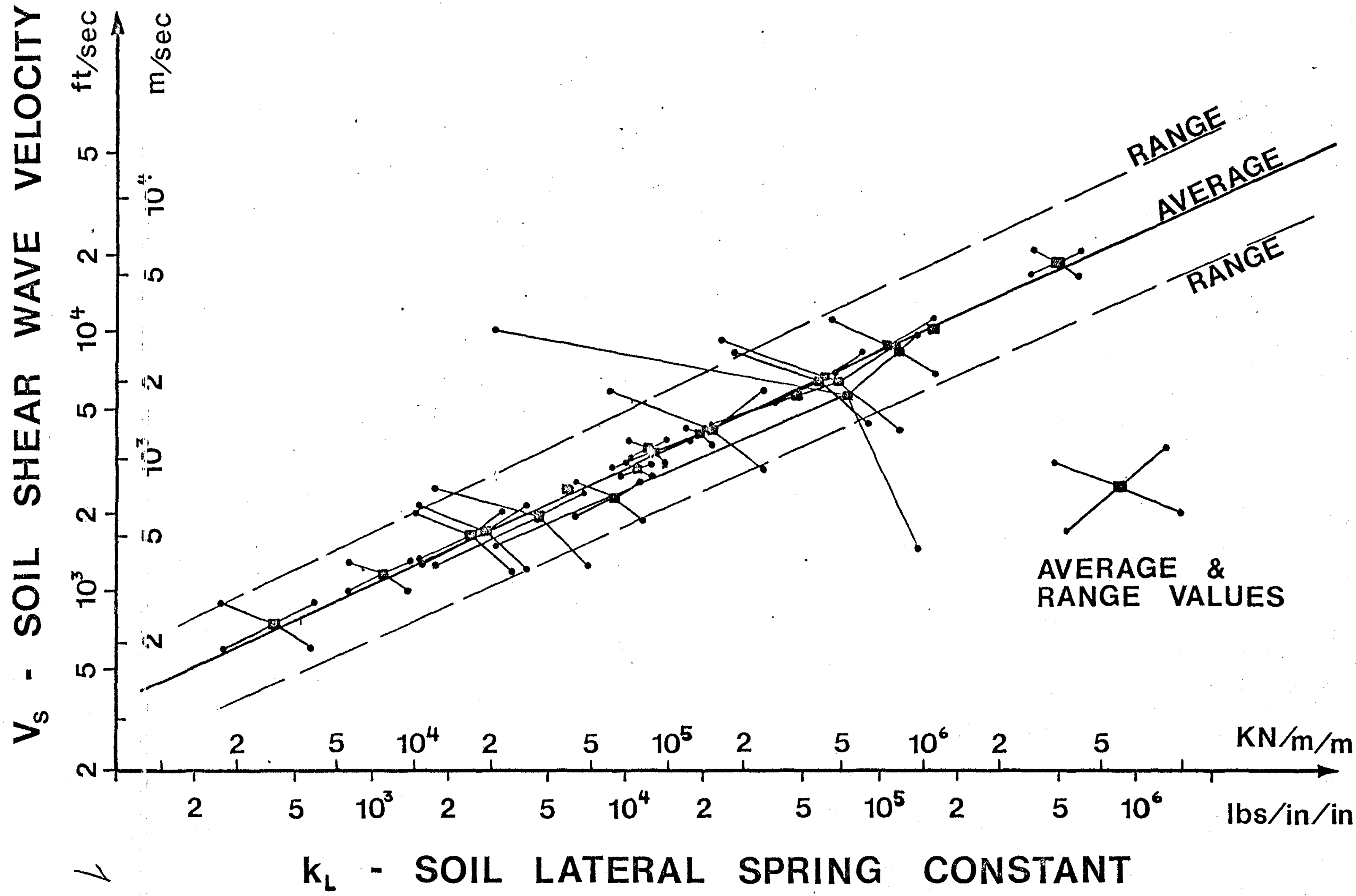

Fig. a - k_L - V_s Relationship
(Based on data given by McClure et al[(d)])

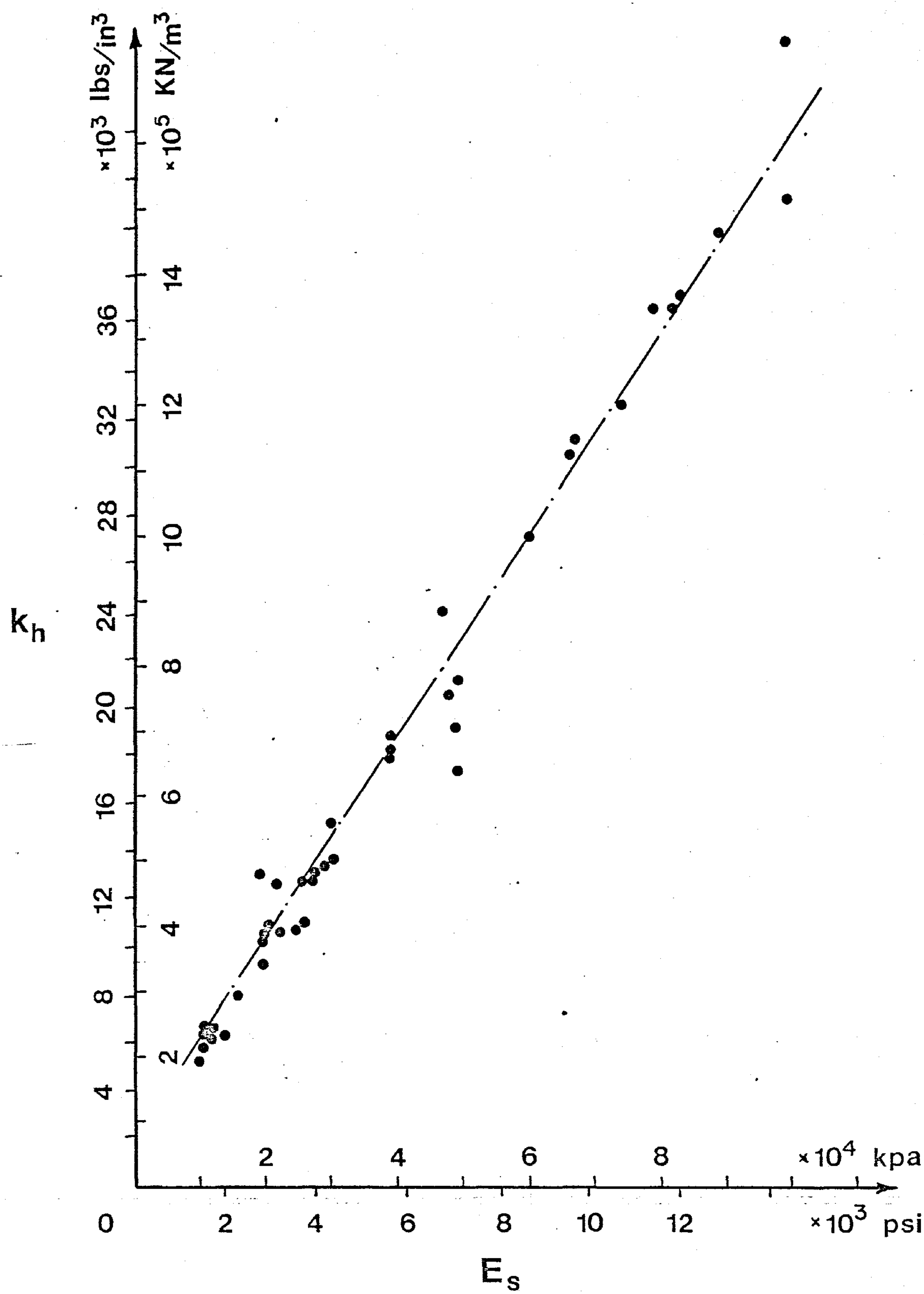

Fig. b - k_h - E_s Relationship
(Based on data given by Kunihiro et al(c))