APPENDIX 20

GEOTECHNICAL REPORT • DISCUSSION OF DERIVATION OF COEFFICIENTS OF SUBGRADE REACTION

The information contained in this appendix was not revised, but has been extracted from the original FSAR and is provided for historical information.

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March 22, 1978
Project 77386
File No. 2.0

Mr. John Herrin
Public Service Co. of New Hampshire
1000 Elm Street - 11th Floor
Manchester, NH 03105

Subject: Discussion of Derivation of Coefficients of Subgrade Reaction

Dear Mr. Herrin:

In the following we describe some techniques that we have developed to convert the moduli obtained from triaxial tests to moduli of subgrade reaction for various loading conditions. We present this information to complement various telephone conversations with D. Patel of UE&C.

Computation of Coefficients of Subgrade Reaction

The coefficient of subgrade reaction, k_s, represents soil deformation, due to pressure acting along a boundary surface, as if the soil were composed of independent springs, each representing a unit of area with a spring constant k_s. The spring constant is defined as a pressure divided by a displacement. Such a representation is convenient for analytical purposes but neglects the influence of adjacent loaded surface areas on the displacement of any given point on the boundary surface. Thus, the coefficient of subgrade reaction is not a unique number for an elastic material but is a function of the size of the loaded area, the pressure distribution, and the geometry of the material. For a soil, the modulus of subgrade reaction is also dependent on the method or sequence of loading, i.e., the stress path.

On the basis of the theory of elasticity, we have computed coefficients of subgrade reaction for the structural backfill and the sand cement for three geometries of loading using the modulus of elasticity and Poisson's ratio data obtained in the triaxial test results. The geometries of loading studied are illustrated in Figs. 1 through 9 and are as follows:

1. Circular or square footing subjected to vertical load.

2. Pressure inside a cylindrical cavity in the soil mass assuming a plane strain condition. This is representative, for example, for the loading produced by thermal expansion of the cross section of a buried pipe.

3. Pressure inside a cylindrical cavity with simultaneous application of a vertical surcharge, p, and a horizontal pressure, $k_o p$. This loading is an approximate representation of the placement of fill over a buried pipe, which deforms to produce an increased lateral stress around the pipe. A plane strain condition was assumed.

The modulus of elasticity and Poisson's ratio used in the computations are strain dependent and were selected for the average strain in the region of the soil mass that contributes most to the displacements, namely, within a distance of one diameter from the pipe and one footing width below the footing base. These strains were correlated with the displacements which, in turn, were expressed in terms of footing settlement divided by footing width, 6/B, or in terms of the diameter strain of the pipe, ε_d. In Figs. 1 through 9, the values of the coefficient of subgrade reaction are plotted as a function of (T/B or ε_d and confining pressure. Confining pressure is to be taken as the effective overburden pressure computed at the elevations shown in the figures. An exception to the above procedure is that for the surcharge type loading, a constant Poisson's ratio of 0.3 was used.

The elastic modulus E and Poisson's ratio v used as a basis for the coefficient of subgrade reaction computations were obtained from triaxial compression tests in which the minor principal stresses were kept constant and the major principal stress was increased monotonically until the specimen failed. Such a stress path would be sufficient to determine E and v for an elastic material. However, soil is not elastic and E and v are dependent on the stress path or stress history. In particular, higher values of E would be obtained for repeated or cyclic loading. For the static load conditions, we feel that the values of subgrade reaction presented are reasonable estimates for the in-situ loading conditions. As shown in the next section, the values compare well with values given in published literature. We recommend, however, that when these values are used, sensitivity analyses should be made to assure that the designs are safe for a range 25% above and below the given values.

Comparison With Published Coefficients of Subgrade Reaction

The coefficients of subgrade reaction obtained from the GEI tests were compared with data presented by K. Terzaghi in the paper entitled

"Evaluation of Coefficients of Subgrade Reaction ," *Geotechnique,* vol. 5, 1955, pp. 297-326.

For shallow footings the vertical coefficient of subgrade reaction for a one square foot plate, k_{s1}, is estimated by Terzaghi to range between 300 and 1,000 ton/cu ft for dense sands, i.e., a range for k_{s1} x B of 4,000 to 14,000 psi. These values are intended for shallow footings, e.g., a typical depth of embedment, D_f, of 4 ft, and for a width, B, of one foot. Thus, they are representative of confining pressures equivalent to a depth of 4.5 ft or about 4 psi.

The coefficient of horizontal subgrade reaction is given by Terzaghi for a 1 sq ft vertical area at a given depth, and it is assumed to be proportional to the effective stress at that depth. For example, for dense sands at a confining pressure of 10 psi, a range of $k_s D$ of 7,000 to 14,000 psi is indicated.

The GEI data for structural backfill, for strains of about 1%, Figs. 1, 2, 4 and 5, agree with Terzaghi's data. No specific information on strain level is given by Terzaghi for his data, but he indicates that the data are applicable to a factor of safety against bearing capacity failure that is larger than two. It is also implicit that the factor of safety would not be much more than 2. Perhaps it lies in the range of 2 to 4. For such factors of safety, the results of plate load tests on sands (1 sq ft plate) would indicate typical settlements of 0.1 in. to 0.3 in., which would be equivalent to a vertical strain on the order of 1% in the soil adjacent to the plate. Thus, the data for the structural backfill obtained from the triaxial tests correspond to coefficients of subgrade reaction within the range given by Terzaghi.

Sincerely yours,

GEOTECHNICAL ENGINEERS INC.

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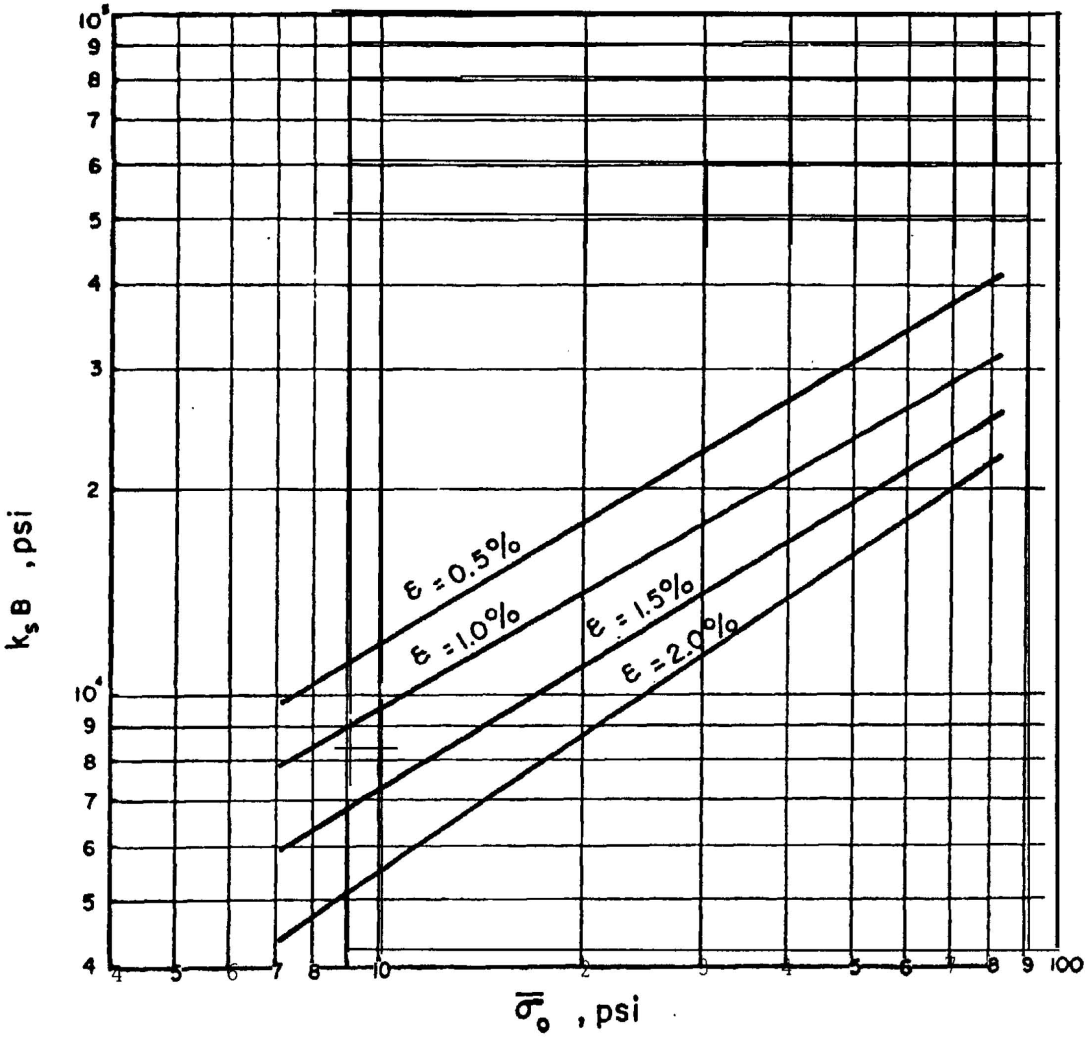
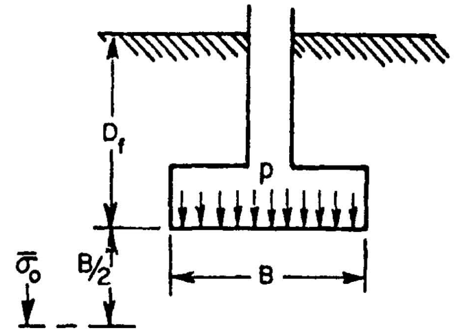
FIGURES





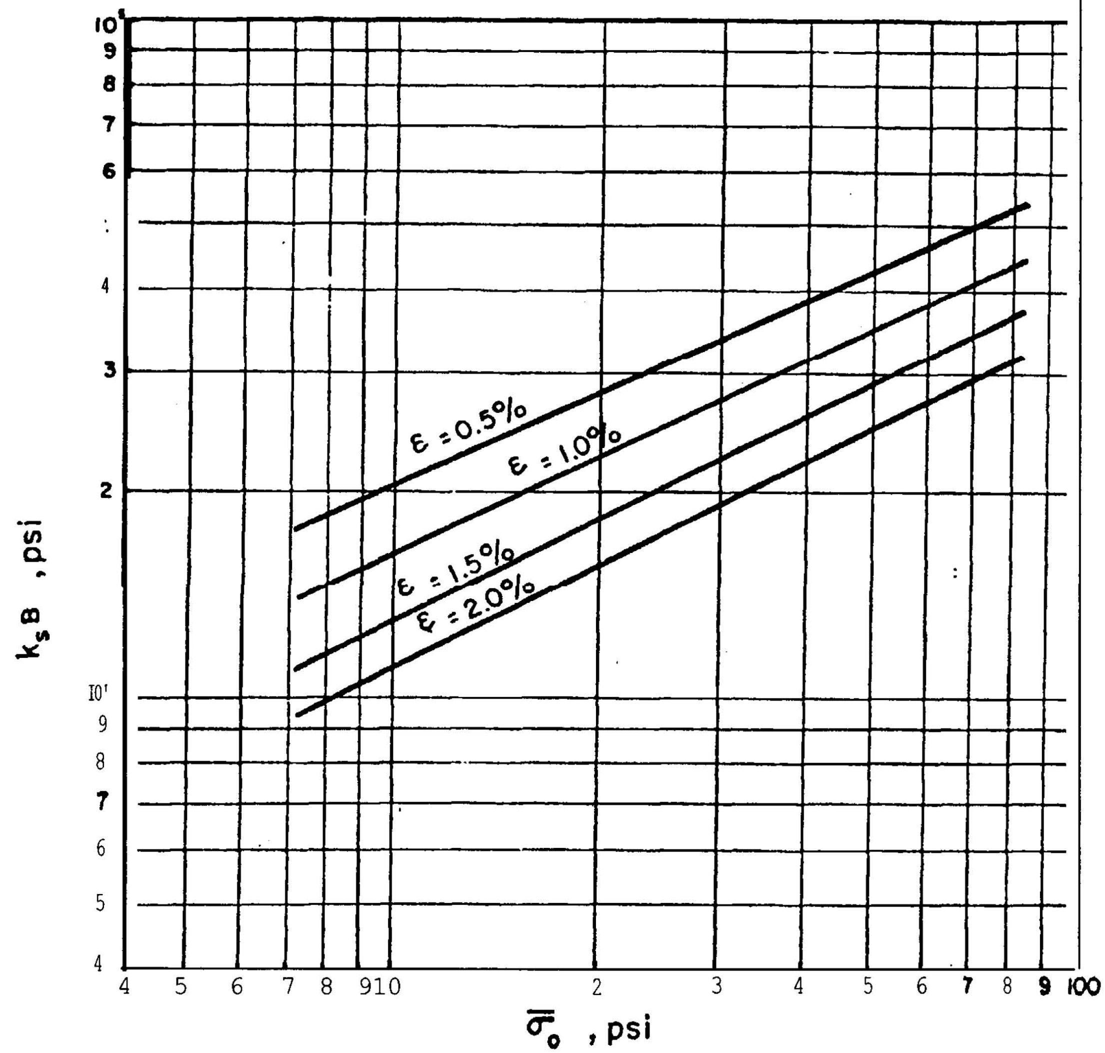
δ = SETTLEMENT

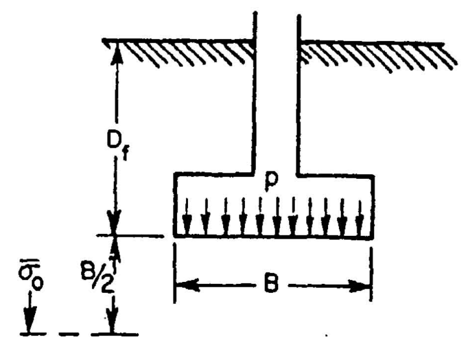
$k = \frac{p}{\delta}$

$\varepsilon = \frac{\delta}{B}$

$\bar{\sigma}_o$ = EFFECTIVE VERTICAL STRESS AT DEPTH (D_f t B/2)

Public Service Company of New Hampshire	**Subgrade** Reaction Sand and Sand-Cement Backfill	FOOTING PRESSURE ON **STRUCTURAL** BACKFILL 90% COMPACTION
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 77386	March 13, 3.978 Fig. 1





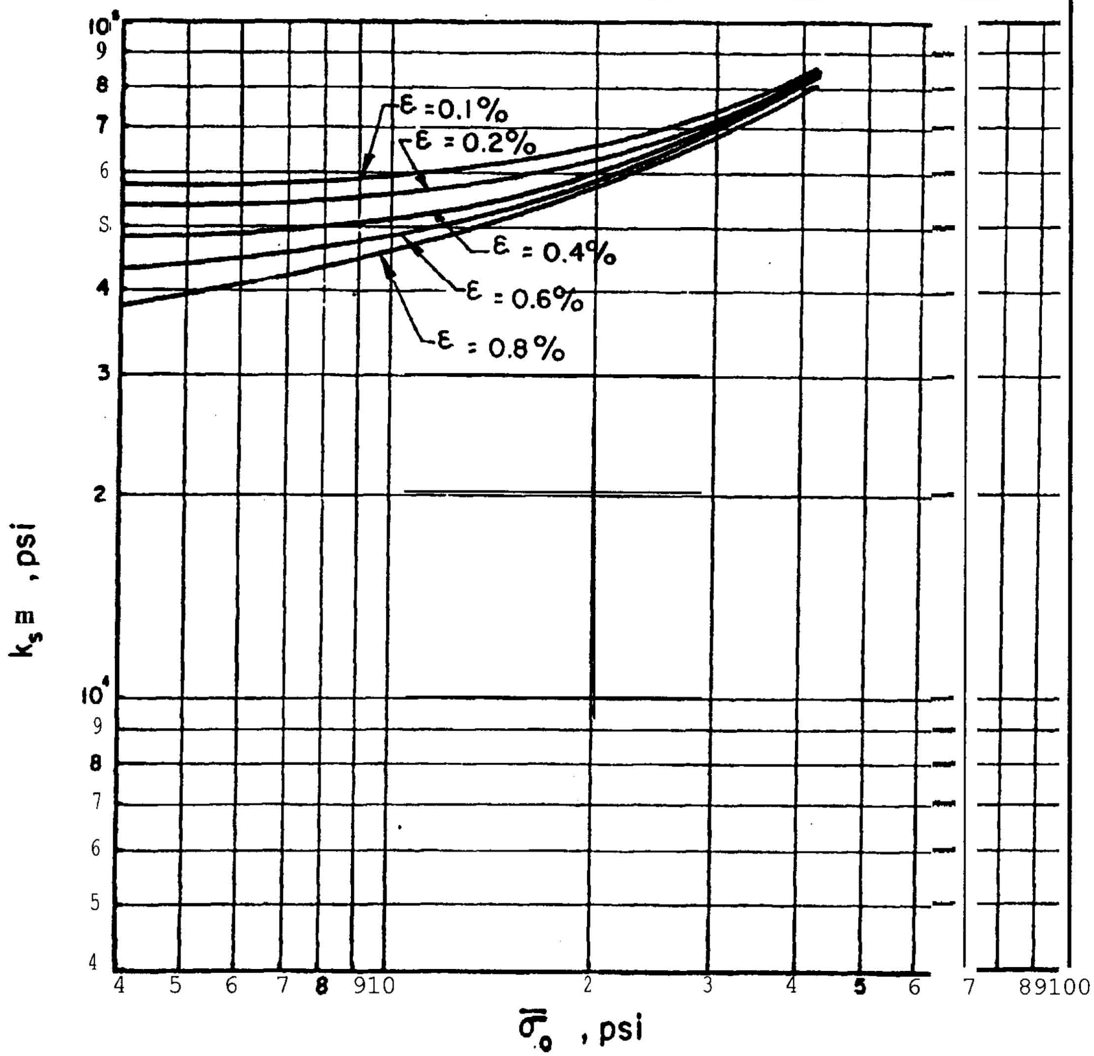
δ = SETTLEMENT

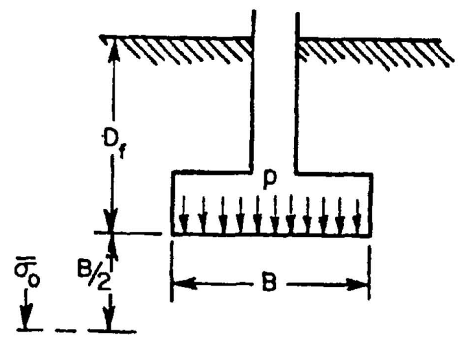
$k = \frac{p}{\delta}$

$\varepsilon = \frac{\delta}{B}$

$\bar{\sigma}_o$ = EFFECTIVE VERTICAL STRESS AT DEPTH (D_f t B/2)

Public Service Company of New Hampshire	**Subgrade** Reaction Sand and Sand-Cement Backfill	FOOTING PRESSURE ON STRUCTURAL BACKFILL 95% COMPACTION
Geotechnical **Engineers** Inc. Winchester, Massachusetts	Project,.77386	March 13, 1978 Fig. 2





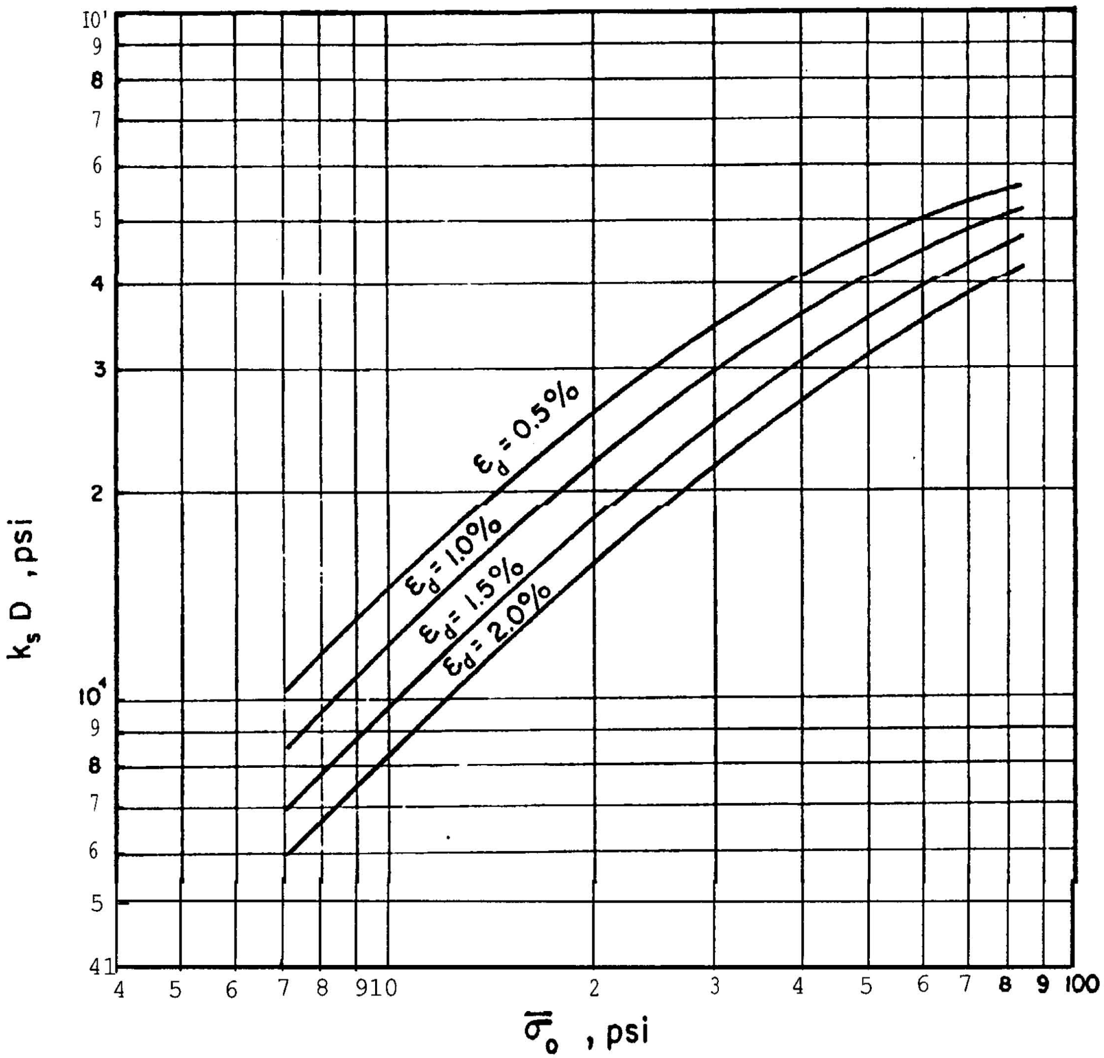
δ = SETTLEMENT

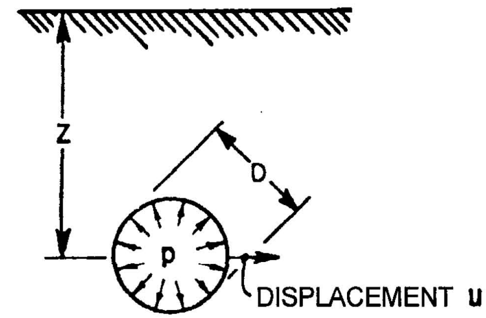
$k = \frac{p}{\delta}$

$\varepsilon = \frac{\delta}{B}$

$\bar{\sigma}_o$ = EFFECTIVE VERTICAL STRESS AT DEPTH (D_f + B/2)

Public Service Company of New Hampshire	Subgrade Reaction Sand and Sand-Cement Backfill	FOOTING PRESSURE ON SAND-CEMENT BACKFILL
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 77386	March 13, 1978 Fig.3



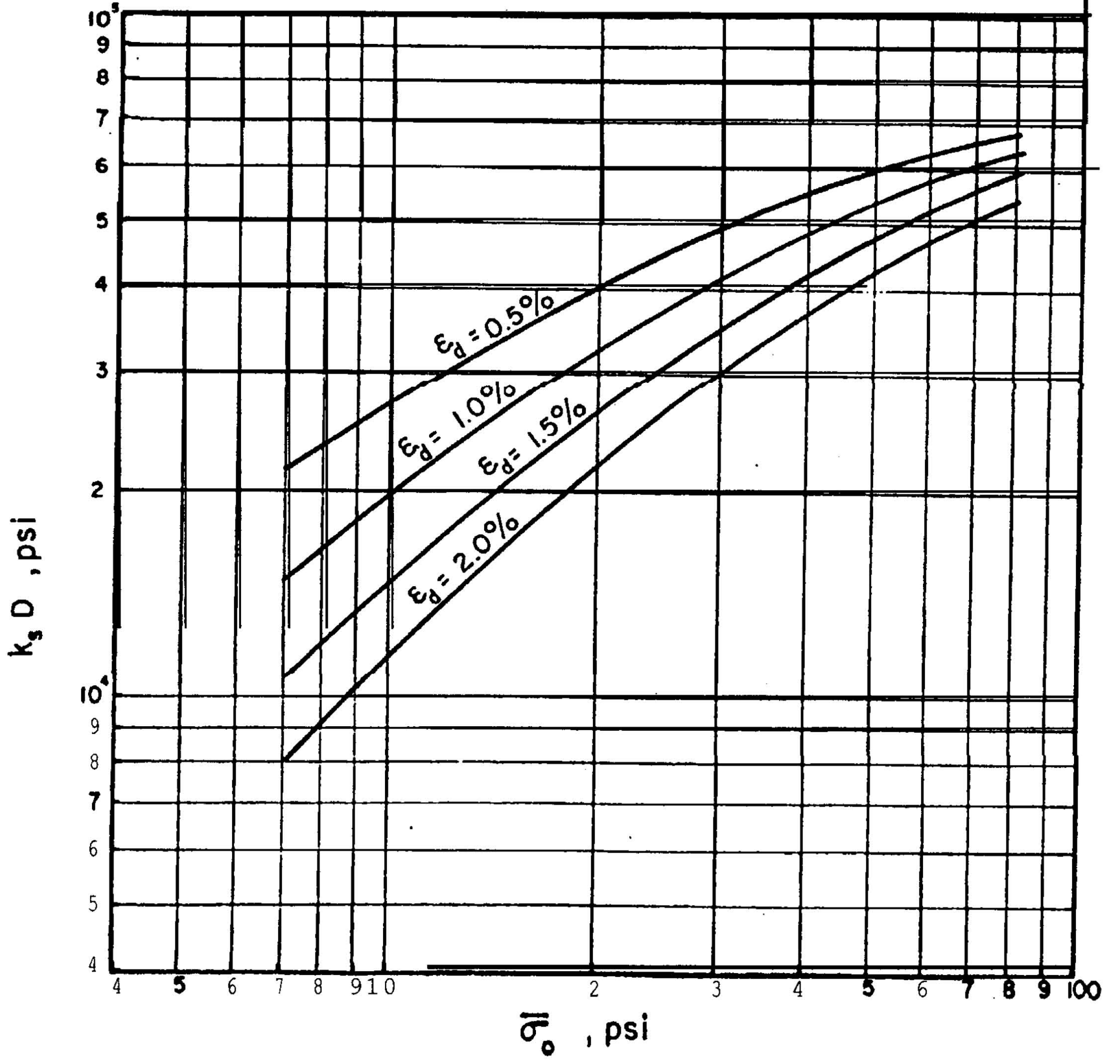


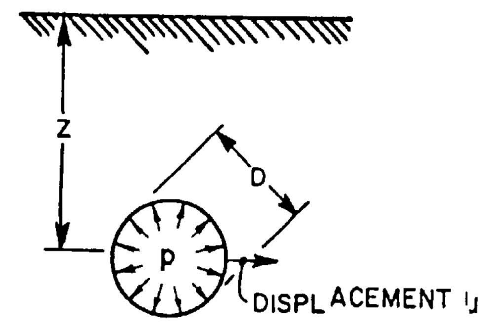
$k_s = \frac{p}{u}$

$\bar{\sigma}_o$ = EFFECTIVE VERTICAL STRESS AT DEPTH Z

$\varepsilon_d = \frac{2u}{D}$

Public Service Company of New Hampshire	Subgrade Reaction Sand and Sand-Cement Backfill	INTERNAL PRESSURE PIPE BURIED IN STRUCTURAL BACKFILL 90% COMPACTION
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 77386	March 13, 1978 Fig. 4



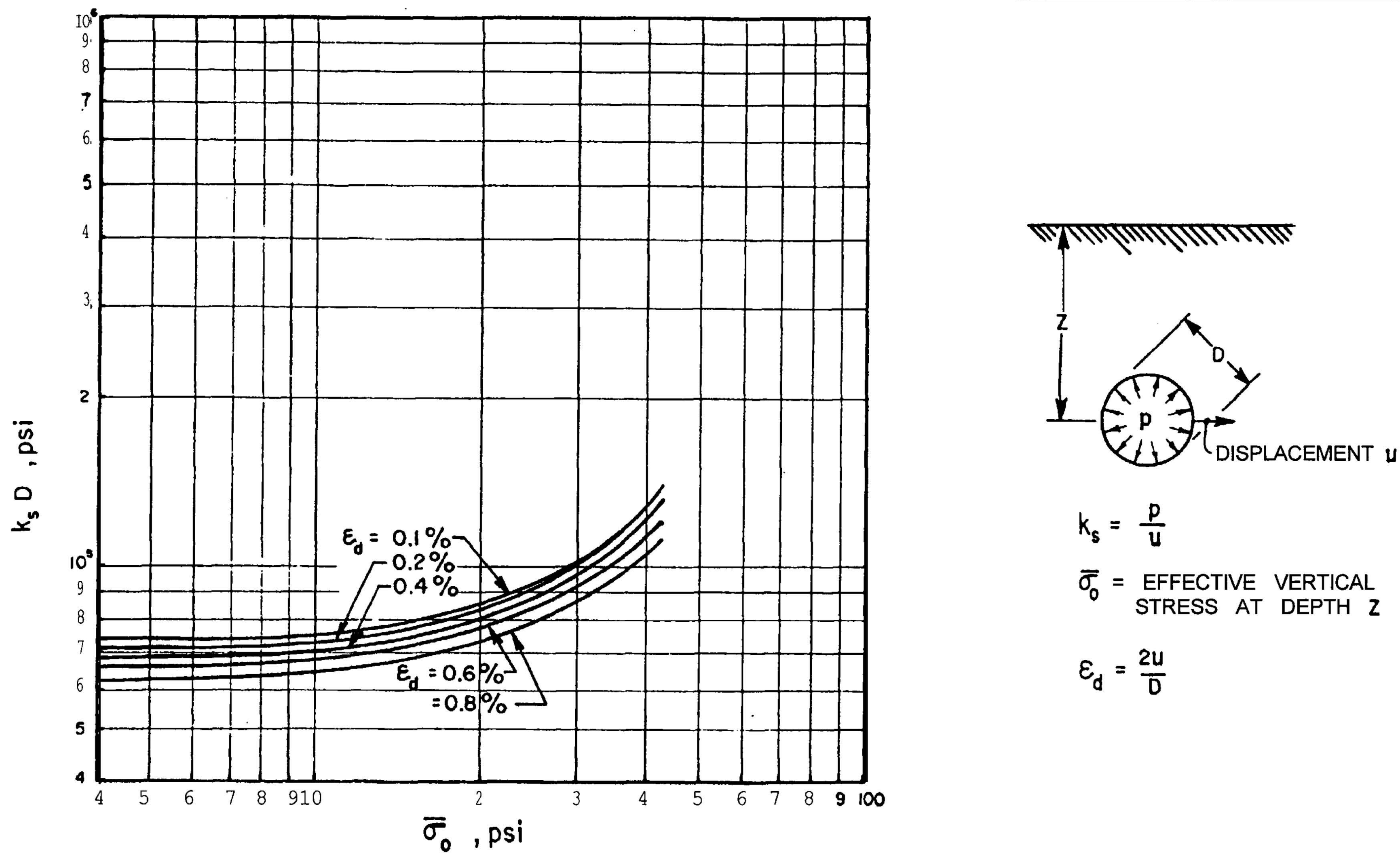


$k_s = \frac{p}{u}$

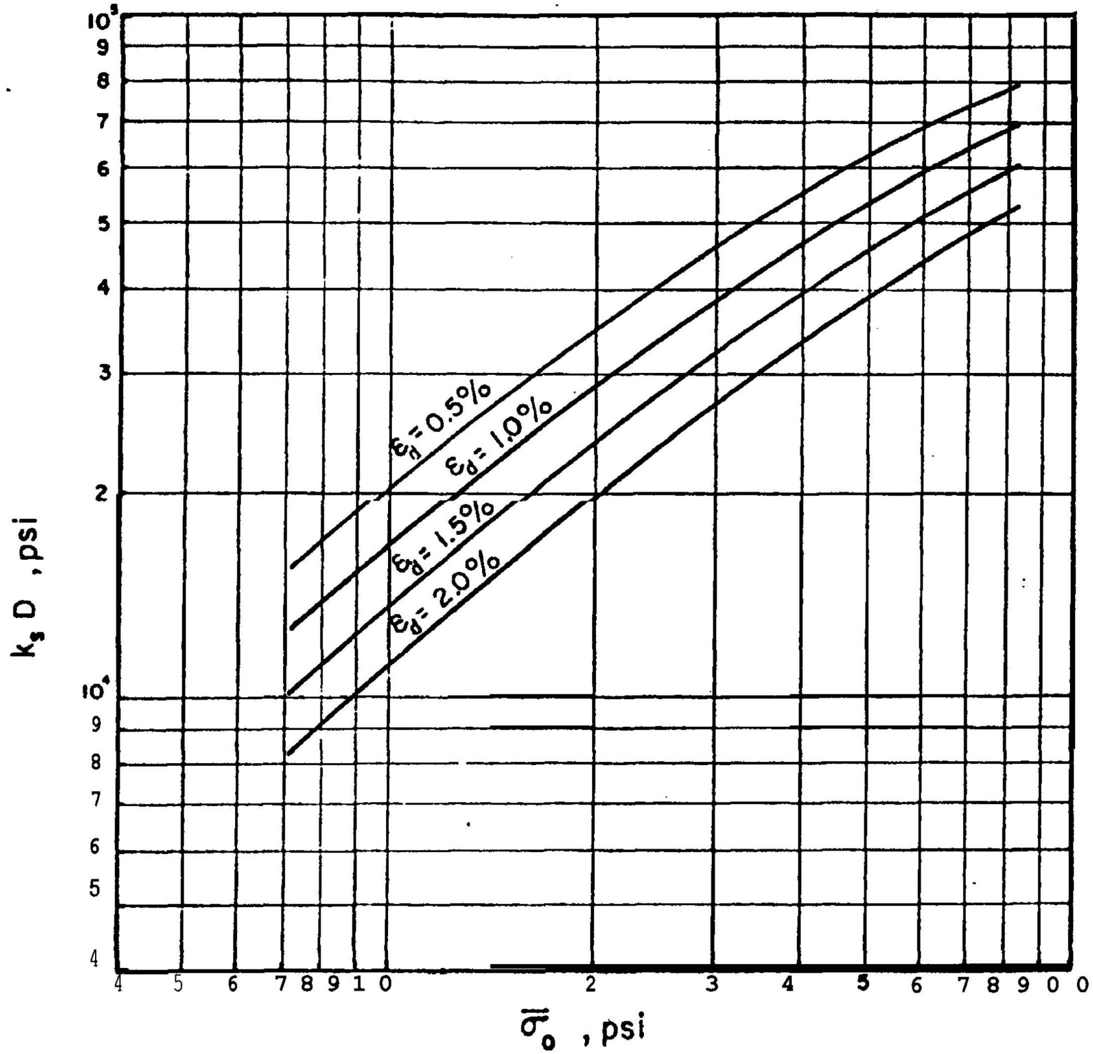
$\bar{\sigma}_o$ = EFFECTIVE VERTICAL STRESS AT DEPTH Z

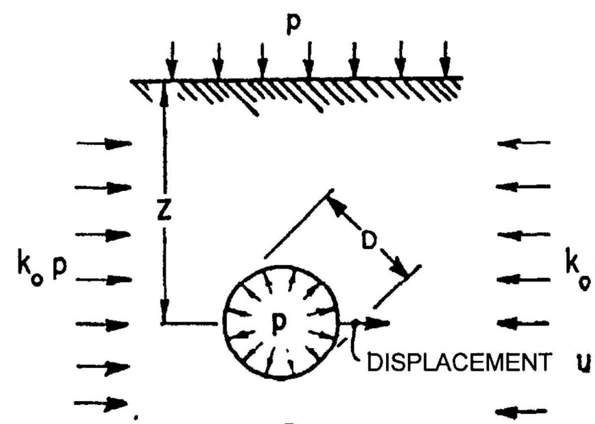
$\varepsilon_d = \frac{2u}{D}$

Public Servide Company of New Hampshire	Subgrade Reaction Sand and Sand-Cement Backfill	INTERNAL PRESSURE PIPE BURIED IN STRUCTURAL BACKFILL 95% COMPACTION
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 77386	March 13, 1978 Fia. 5



Public Service Company of New **Hampshire**	**Subgrade** Reaction Sand and Sand-Cement Backfill	INTERNAL PRESSURE PIPE BURIED IN SAND-CEMENT BACKFILL
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 77386	March 13, 1978 Fig. 6



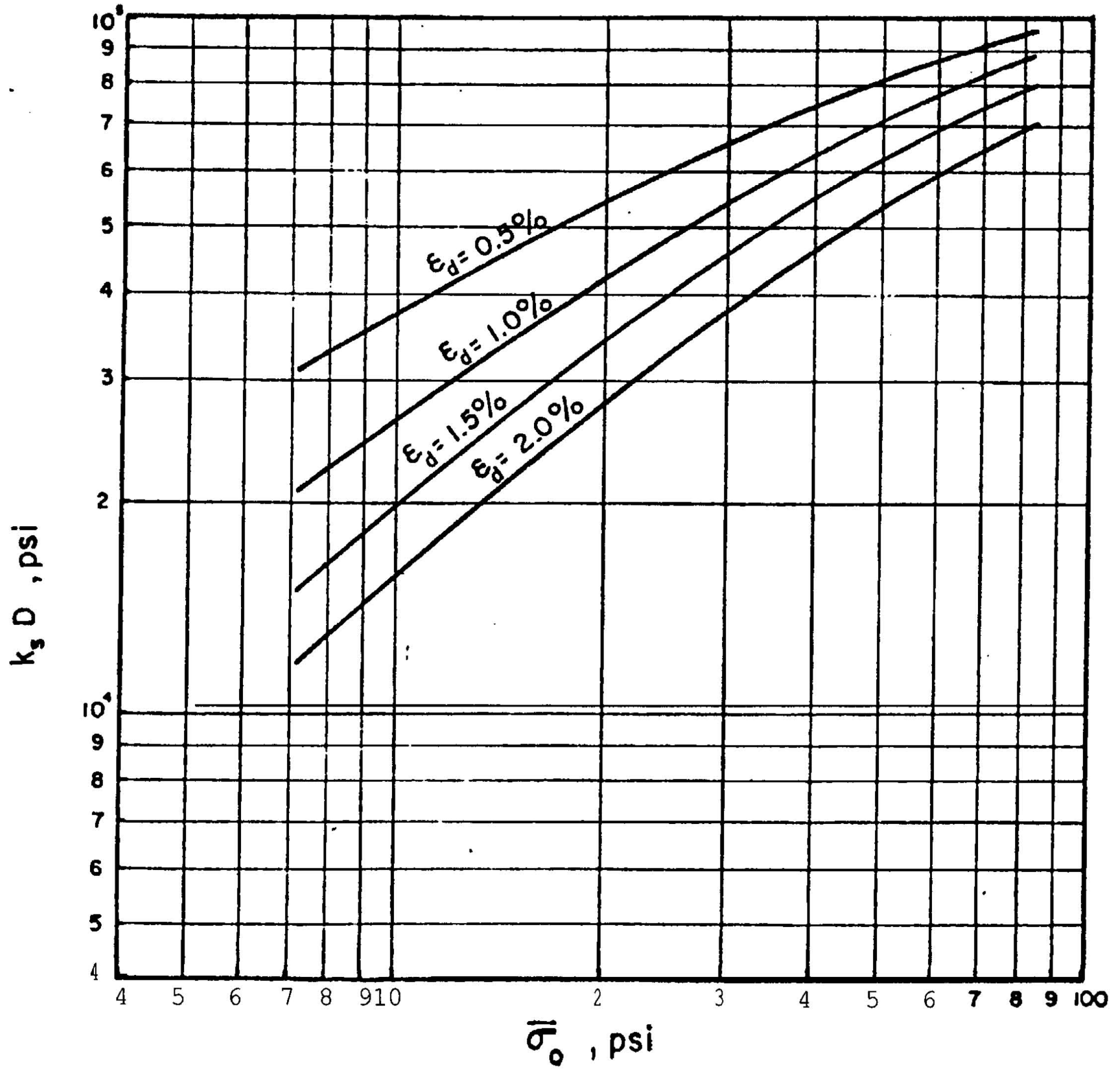


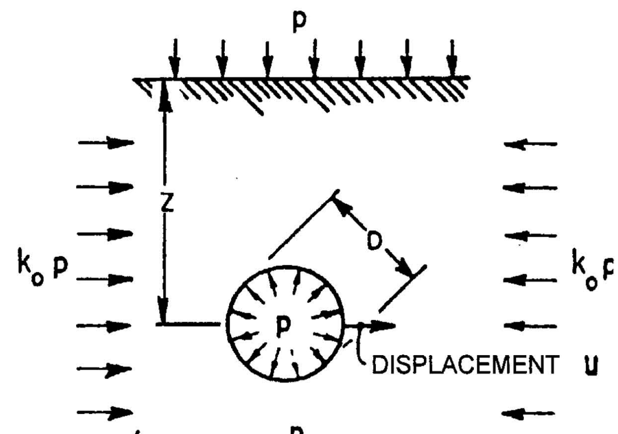
$k_s = \frac{p}{u}$

$\varepsilon_d = \frac{2u}{D}$

$\bar{\sigma}_o$ = EFFECTIVE VERTICAL STRESS AT DEPTH Z

Public Service Company of New Hampshire	Subgrade Reaction Sand and Sand-Cement Backfill	SURCHARGE PRESSURE ON PIPE IN STRUCTURAL BACKFILL 90% COMPACTION
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 77386	March 13, 1978 Fig. 7



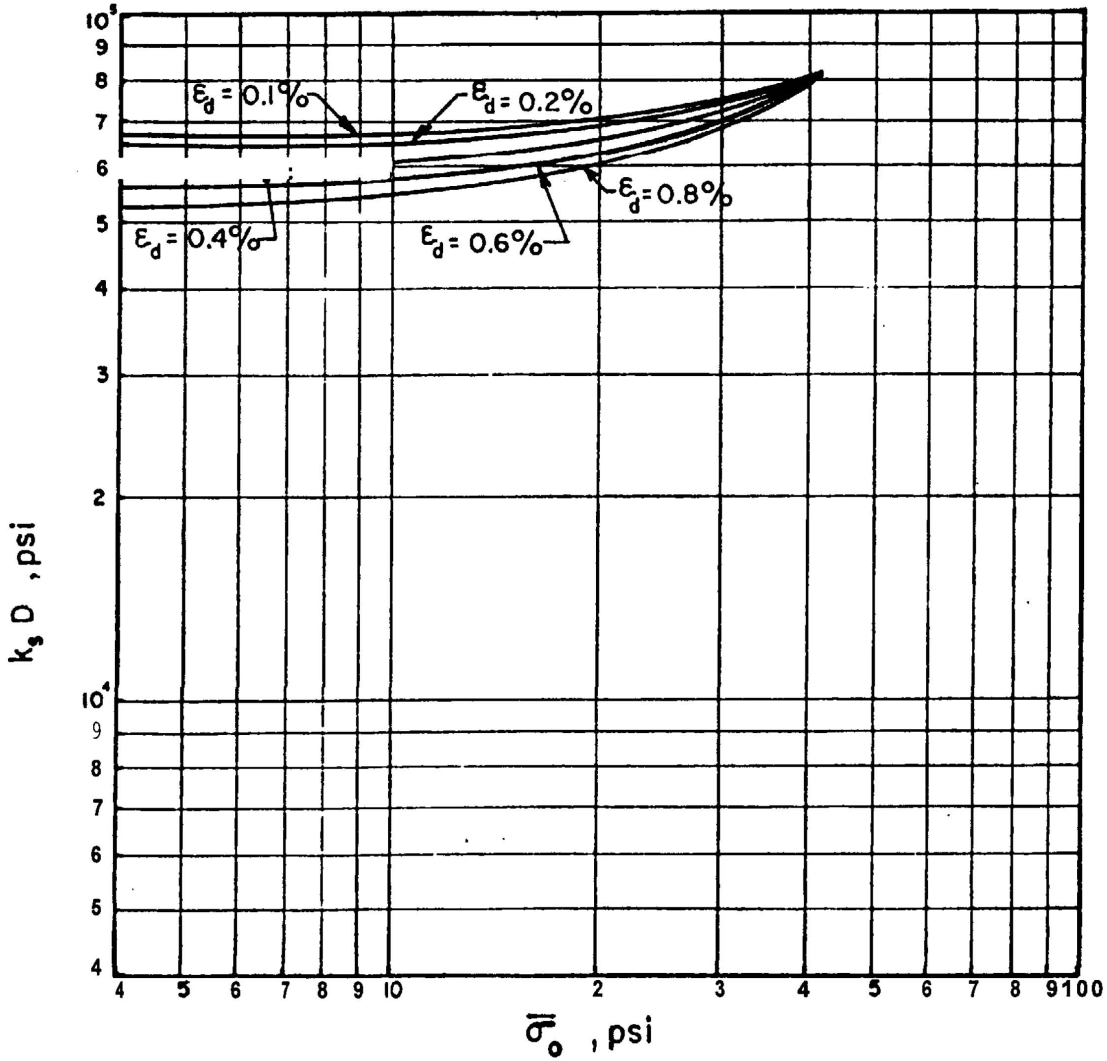


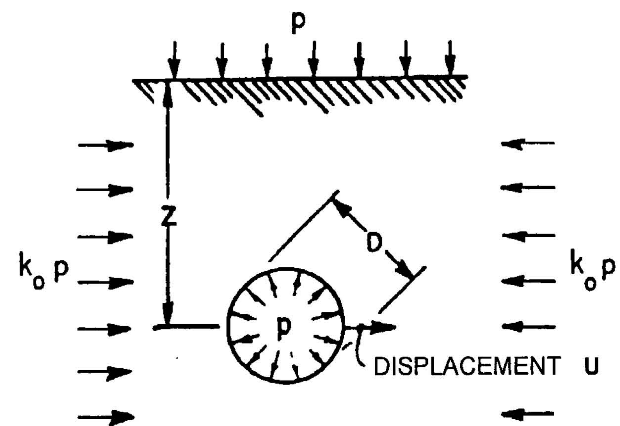
$k_s = \frac{p}{u}$

$\varepsilon_d = \frac{2u}{D}$

$\bar{\sigma}_o$ = EFFECTIVE VERTICAL STRESS AT DEPTH Z

Public Service Company of New Hampshire	**Subgrade** Reaction Sand and Sand-Cement Backfill	SURCHARGE PRESSURE ON PIPE IN STRUCTURAL BACKFILL '95% COMPACTION
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 77386	March 13, 1978 Fig. 8





$$k_s = \frac{p}{u}$$

$$\varepsilon_d = \frac{2u}{D}$$

$\overline{\sigma_o}$ = EFFECTIVE VERTICAL STRESS AT DEPTH Z

Public Service Company of New Hampshire	Subgrade Reaction Sand and Sand-Cement Backfill	SURCHARGE PRESSURE ON PIPE IN SAND-CEMENT BACKFILL
Geotechnical Engineers Inc.. Winchester, Massachusetts	Project 77386	March 13, 1978 Fig. 9