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Suggested Analysis and Design Procedures for Combined Footings and Mats

Reported by ACI Committee 336

Edward J. Ulrich
Chair

Shyam N. Shukla
Secretary

Clyde N. Baker, Jr.
Steven C. Ball
Joseph E. Bowles
Joseph P. Colaco
M. T. Davisson
John A. Focht, Jr.
M. Gaynor
John P. Gnaedinger
Fritz Kramrisch
Hugh S. Lacy
Jim Lewis
James S. Notch
Ingvar Schousboe
John F. Seidensticker
Bruce A. Suprenant
Jagdish S. Syal
John J. Zils

This report deals with the design of foundations carrying more than a single column of wall load. These foundations are called combined footings and mats. Although it is primarily concerned with the structural aspects of the design, considerations of soil mechanics cannot be eliminated and the designer should focus on the important interrelation of the two fields in connection with the design of such structural elements. This report is limited to vertical effects of all loading conditions. The report excludes slabs-on-grade.

Keywords: concretes; earth pressure; footings; foundations; loads (forces); mat foundations; reinforced concrete; soil mechanics; stresses; structural analysis; structural design.

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CHAPTER 1—GENERAL

1.1—Notation

The following dimensioning notation is used: F = force; ℓ = length; and Q = dimensionless.

A = base area of footing, ℓ^2
b = width of pressed edge, ℓ
B = foundation width, or width of beam column element, ℓ
B_m = mat width, ℓ
B_p = plate width, ℓ
c = distance from resultant of vertical forces to overturning edge of the base, ℓ
D = dead load or related internal moments and forces, F
D_f = the depth D_f should be the depth of soil measured adjacent to the pressed edge of the combined footing or mat at the time the loads being considered are applied
D_o = dead load for overturning calculations, F
D_{st} = stage dead load consisting of the unfactored dead load of the structure and foundation at a particular time or stage of construction, F
e = eccentricity of resultant of all vertical forces, ℓ
e_i = eccentricity of resultant of all vertical forces with respect to the x- and y-axes (e_x and e_y, respectively), ℓ
E = vertical effects of earthquake simulating forces or related internal moment or force, F
E' = modulus of elasticity of the materials used in the superstructure, F/ℓ^2
E_e = modulus of elasticity of concrete, F/ℓ^2
E_s = soil modulus of elasticity, F/ℓ^2
F_{vh} = vertical effects of lateral loads such as earth pressure, water pressure, fill pressure, surcharge pressure, or similar lateral loads, F
G = shear modulus of concrete, F/ℓ^2
h_w = height of any shearwalls in structure, ℓ
H = settlement of foundation or point, ℓ
H_{ci} = consolidation (or recompression) settlement of point i, ℓ
ΔH = magnitude of computed foundation settlement, ℓ
I = plan moment of inertia of footing (or mat) about any axis $x(I_x)$ or $y(I_y)$, ℓ^4
I_B = moment of inertia of one unit width of the superstructure, ℓ^4
I_F = moment of inertia per one unit width of the foundation, ℓ^4
I_w = base shape factor depending on foundation shape and flexibility, ℓ^4
i = vertical displacement of a node, ℓ
J = torsion constant for finite grid elements, ℓ^4
k_p = coefficient of subgrade reaction from a plate load test, F/ℓ^3
k_s = q/δ = coefficient (or modulus) of vertical subgrade reaction; generic term dependent on dimensions of loaded area, F/ℓ^3
k_{si} = coefficient of subgrade reaction contribution to node i, F/ℓ^3
k'_{si} = revised coefficient of subgrade reaction contribution to node i, F/ℓ^3, see Section 6.8
k_{v1} = basic value of coefficient of vertical subgrade reaction for a square area with width B = 1 ft, F/ℓ^3
K = spring constant computed as contributory node area xk_s, F/ℓ
K_r = relative stiffness factor for foundation, Q
L = live load or related internal moments and forces produced by the load, F
L_s = sustained live loads used to estimate settlement, F. A typical value would be 50% of all live loads.
L_{st} = stage service live load consisting of the sum of all unfactored live loads at a particular stage of construction, F
M' = bending moment per unit length, $F\ell$
M_E = overturning moment about base of foundation caused by an earthquake simulating force, $F\ell$
M_F = overturning moment about base of foundation, caused by F_{vh} loads, $F\ell$
M_o = largest overturning moment about the pressed edge or centroid of the base, $F\ell$
M_R = resultant resisting moment, $F\ell$
M_W = overturning moment about base of foundation, caused by wind loads, blast, or similar lateral loads, $F\ell$
n = exponent used to relate plate k_p to mat k_s, Q
P = any force acting perpendicular to base area, F
q = soil contact pressure computed or actual, F/ℓ^2
q_a = allowable soil contact pressure, F/ℓ^2
q_i = actual or computed soil contact pressure at a node point as furnished by the mat analysis. The contact pressures are evaluated by the geotechnical analysis for compatibility with q_a and foundation movement, F/ℓ^2
q_u = unconfined (undrained) compression strength of a cohesive soil, F/ℓ^2
q_{ult} = ultimate soil bearing capacity; a computed value to allow computation of ultimate strength design moments and shears for the foundation design, also used in overturning calculations, F/ℓ^2

R_v = resultant of all given design loads acting perpendicular to base area, F

$R_{v\,min}$ = least resultant of all forces acting perpendicular to base area under any condition of loading simultaneous with the overturning moment, F

S = section modulus of mat plan area about a specified axis; S_x about x-axis; S_y about y-axis, ℓ^3

SR = stability ratio (formerly safety factor), Q

t_w = thickness of shearwalls, ℓ

v = distance from the pressed edge to $R_{v\,min}$ (see Fig. 4.1 and 4.2), ℓ

W = vertical effects of wind loads, blast, or similar lateral loads, F

X_i = the maximum deflection of the spring at node i as a linear model, ℓ

Z = foundation base length or length of beam column element, ℓ

Z' = footing effective length measured from the pressed edge to the position at which the contact pressure is zero, ℓ

δ = vertical soil displacement, ℓ

Δ_q = average increase in soil pressure due to unit surface contact pressure, F/ℓ^2

λ = footing stiffness evaluation factor defined by Eq. (5-3), $1/\ell$

μ = Poisson's ratio, Q

Σ = summation symbol, Q

γ = unit weight of soil, F/ℓ^3

$\propto$ = torsion constant adjustment factor, Q

1.2—Scope

This report addresses the design of shallow foundations carrying more than a single column or wall load. Although the report focuses on the structural aspects of the design, soil mechanics considerations are vital and the designer should include the soil-structure interaction phenomenon in connection with the design of combined footings and mats. The report excludes slabs-on-grade.

1.3—Definitions and loadings

Soil contact pressures acting on a combined footing or mat and the internal stresses produced by them should be determined from one of the load combinations given in Section 1.3.2, whichever produces the maximum value for the element under investigation. Critical maximum moment and shear may not necessarily occur with the largest simultaneously applied load at each column.

1.3.1 *Definitions*

coefficient of vertical subgrade reaction k_s—ratio between the vertical pressure against the footing or mat and the deflection at a point of the surface of contact

$$k_s = q/\delta$$

combined footing—a structural unit or assembly of units supporting more than one column load.

contact pressure q—pressure acting at and perpendicular to the contact area between footing and soil, produced by the weight of the footing and all forces acting on it.

continuous footing—a combined footing of prismatic or truncated shape, supporting two or more columns in a row.

grid foundation—a combined footing, formed by intersecting continuous footings, loaded at the intersection points and covering much of the total area within the outer limits of assembly.

mat foundation—a continuous footing supporting an array of columns in several rows in each direction, having a slab-like shape with or without depressions or openings, covering an area of at least 75% of the total area within the outer limits of the assembly.

mat area—contact area between mat foundation and supporting soil.

mat weight—weight of mat foundation.

modulus of subgrade reaction—see **coefficient of vertical subgrade reaction**.

overburden—weight of soil or backfill from base of foundation to ground surface. Overburden should be determined by the geotechnical engineer.

overturning—the horizontal resultant of any combination of forces acting on the structure tending to rotate the structure as a whole about a horizontal axis.

pressed edge—edge of footing or mat along which the greatest soil pressure occurs under the condition of overturning.

soil stress-strain modulus—modulus of elasticity of soil and may be approximately related (Bowles 1982) to the coefficient of subgrade reaction by the equation

$$E_s = k_s B(1 - \mu^2) I_w$$

soil pressure—see **contact pressure**.

spring constant—soil resistance in load per unit deflection obtained as the product of the contributory area and k_s. See also **coefficient of vertical subgrade reaction**.

stability ratio (*SR*)—formally known as safety factor, it is the ratio of the resisting moment M_R to the overturning moment M_o.

strip footing—see **continuous footing**.

subgrade reaction—see **contact pressure** and Chapter 3.

surcharge—load applied to ground surface above the foundation.

1.3.2 *Loadings*—Loadings used for design should conform to the considerations and factors in Chapter 9 of ACI 318 unless more severe loading conditions are required by the governing code, agency, structure, or conditions.

1.3.2.1 *Dead loads*—Dead load D consisting of the sum of:

a. Weight of superstructure.

b. Weight of foundation.

c. Weight of surcharge.

d. Weight of fill occupying a known volume.

1.3.2.2 *Live loads*—Live load L consisting of the sum of:

a. Stationary or moving loads, taking into account allowable reductions for multistory buildings or large floor areas, as stated by the applicable building code.