

# Suggested Analysis and Design Procedures for Combined Footings and Mats

Reported by ACI Committee 336

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*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;  $\ell$  = length; and  $Q$  = dimensionless.

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

|              |  |
|--------------|--|
| $R_v$        | = 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, $\ell^3$                                    |
| $SR$         | = stability ratio (formerly safety factor), $Q$  |
| $t_w$        | = thickness of shearwalls, $\ell$  |
| $v$          | = distance from the pressed edge to $R_{v\ min}$ (see Fig. 4.1 and 4.2), $\ell$  |
| $W$          | = 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, $\ell$   |
| $Z$          | = foundation base length or length of beam column element, $\ell$  |
| $Z'$         | = footing effective length measured from the pressed edge to the position at which the contact pressure is zero, $\ell$                        |
| $\delta$     | = vertical soil displacement, $\ell$   |
| $\Delta_q$   | = average increase in soil pressure due to unit surface contact pressure, $F/\ell^2$   |
| $\lambda$    | = footing stiffness evaluation factor defined by Eq. (5-3), $1/\ell$   |
| $\mu$        | = Poisson's ratio, $Q$   |
| $\Sigma$     | = summation symbol, $Q$  |
| $\gamma$     | = unit weight of soil, $F/\ell^3$  |
| $\alpha$     | = 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:

- Weight of superstructure.
- Weight of foundation.
- Weight of surcharge.
- Weight of fill occupying a known volume.

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

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