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Original article

Code-Based Design and ANSYS-Ready Nonlinear Finite Element Modeling of Isolated and Raft Reinforced Concrete Foundations under ECP 203, ACI 318, and Eurocode 2

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Abstract
This study presents a systematic computational framework for the code-based design and ANSYS-ready nonlinear finite element modeling of isolated and raft reinforced concrete foundations. Thirty base scenarios, comprising 18 isolated footings and 12 raft foundations, were designed according to ECP 203 (2018), ACI 318-19, and Eurocode 2 (EN 1992-1-1), yielding 90 code-specific design alternatives. Each alternative is documented through its geometry, materials, reinforcement, soil-domain dimensions, contact conditions, boundary constraints, and mesh specifications to facilitate reproducible ANSYS model construction. The design database demonstrates that code selection influences foundation thickness, reinforcement demand, material quantities, and governing limit states. For isolated footings, mean thicknesses were 397.22 mm for ECP, 441.67 mm for ACI, and 455.56 mm for EC2; corresponding mean reinforcement weights were 218.38, 166.12, and 182.91 kg, respectively. Flexure governed 43 of the 54 isolated-footing designs and 33 of the 36 raft designs, whereas punching shear and one-way shear governed selected alternatives. The resulting internally verified design database provides a traceable basis for subsequent nonlinear performance assessment under consistent modeling assumptions.
Keywords: Isolated Footings; Raft Foundations; Punching Shear; Soil-Structure Interaction; ECP 203; ACI 318.

Introduction

Shallow reinforced concrete foundations transfer structural loads to the supporting ground and must satisfy structural strength and geotechnical serviceability requirements [1,2]. Established design provisions address flexure, one-way shear, punching shear, reinforcement detailing, and allowable soil pressure, but different standards can lead to distinct design solutions for the same loading and soil conditions [1,2]. Bakhoum et al. [1] compared the action and resistance formats of Egyptian, American, and European codes and demonstrated the importance of considering their safety formats consistently. Abdrabbo et al. [2] emphasized that isolated-footing design combines structural and geotechnical idealizations, particularly in the interpretation of shear and soil reactions.

Recent research has clarified the sensitivity of punching behavior to geometry, reinforcement, and foundation-support conditions. El-Said et al. [3] evaluated code provisions against a large experimental footing database, while Halvonik et al. [4] tested footings on near-natural subsoil conditions. Bonić et al. [5] examined punching resistance while accounting explicitly for soil-structure interaction. El-Naqeeb et al. [6] developed numerical models of reinforced concrete footings subjected to biaxially eccentric loading. Truong and Kim [7] investigated the influence of soil-footing friction on punching strength. Saeed [8] examined the consequences of nonlinear soil behavior for raft response, and Amrane [9] assessed advanced constitutive descriptions of sandy subsoil. More recently, Ors et al. [10] presented laboratory observations on isolated footings on sand, and Yoon and Lee [11] examined settlement estimation for raft-related foundation systems using finite element interaction factors.

Three related issues motivate the present investigation: 1). Integration of design and model preparation: code-based footing comparisons often remain separate from the systematic documentation of inputs required for three-dimensional finite element implementation. 2). Consistency across design standards: comparing different code-generated sections requires a common numerical idealization so that variations in geometry and reinforcement can be distinguished from changes in analysis assumptions, and 3). Raft design comparisons: the combined effects of column layout, global slab geometry, and code-specific detailing merit examination alongside the more widely investigated isolated-footing cases.

The study therefore establishes a traceable multi-code design-to-model workflow. Eighteen isolated-footing scenarios and twelve raft-foundation scenarios were each designed using ECP 203, ACI 318, and Eurocode 2. Their 90 code-specific alternatives were documented through geometry, reinforcement schedules, material assignments, soil-domain dimensions, contact definitions, boundary conditions, and mesh controls. These records allow the structural design consequences of code selection to be quantified independently of the later nonlinear finite element solution stage.

The manuscript contributes:

1. An internally verified database of 90 code-specific foundation designs.
2. Standardized, case-specific input specifications for constructing the corresponding ANSYS models.
3. Quantitative comparisons of thickness, material quantities, reinforcement, bearing utilization, and governing structural checks.
4. A documented framework for subsequent nonlinear assessment using common numerical assumptions.

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Research Gap Identification

The following gaps frame the research problem:

Gap 1

Published footing investigations have assessed punching resistance, soil support, and code equations in considerable detail [3-6]. However, these strands do not always include a complete, auditable record linking the design calculation to every numerical-model input. The present research addresses this documentation gap without equating model preparation with numerical or experimental validation.

Gap 2

Although comparisons of actions and resistance formats have been reported [1,2], systematic comparison of code-specific foundation geometries also requires consistent material, soil, contact, and discretization specifications. Otherwise, differences attributed to the code could be confounded with differences in the numerical representation.

Gap 3

Raft foundations introduce multi-column load transfer, spatial variation in bending, and sensitivity to overall stiffness and support conditions. These considerations motivate a separate raft matrix rather than assuming that conclusions drawn from isolated footings apply directly to rafts.

Novel Contribution

The original contribution lies in integrating three elements within a single traceable procedure:

1. Code-to-model traceability: the geometric dimensions, reinforcement arrangement, material properties, contact definitions, and mesh controls are documented for each code-specific design.
2. Controlled numerical assumptions: material grades, soil categories, interface rules, and discretization criteria are held consistent within each matched scenario, enabling the effects of code-generated geometry and detailing to be examined.
3. Structured coverage: 54 isolated-footing designs and 36 raft-foundation designs span the prescribed load, soil, and column/layout combinations, permitting comparisons within and across foundation systems.

Unlike investigations focused exclusively on punching resistance or soil nonlinearity [3,6,8], this study quantifies the design outputs entering the finite element model and establishes a reproducible input database. The subsequent prediction and validation of nonlinear response remain distinct steps.

Materials and Methods

Computational Design

The investigation uses a controlled, comparative design matrix. The independent variables comprise design standard, foundation type, load level, soil category, and column size or raft layout. The recorded design outputs comprise thickness, reinforcement area, concrete volume, reinforcement weight, shear utilization, bearing utilization, and the governing structural limit state. The matrix consists of 18 isolated-footing scenarios Table 1 and 12 raft scenarios Table 2, with three code-based design alternatives for each scenario.

For isolated footings, three service-load levels (L1-L3), three soil classes (S1-S3), and two square-column sizes (400 × 400 mm and 600 × 600 mm) define the 18 cases. For raft foundations, two column layouts (R1: 3 × 3 columns; R2: 4 × 4 columns), two column-load levels (RL1 and RL2), and three soil classes define the 12 cases.

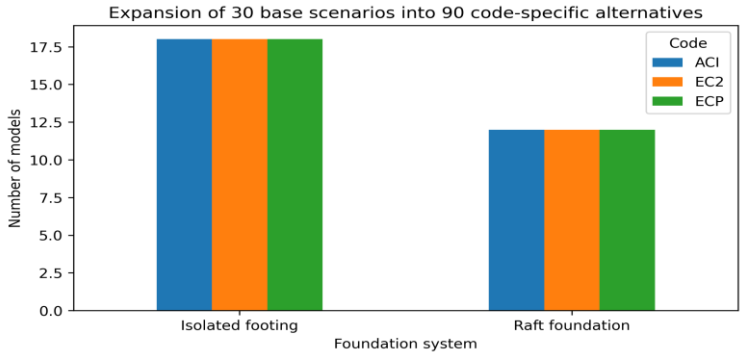


Figure 1. Distribution of the 90 code-specific alternatives generated from the parametric program.

Code-Specific Alternatives: Each base scenario is independently designed according to ACI 318-19 [15], Eurocode 2 EN 1992-1-1 [16], and ECP 203-2018 [17]. This yields 54 isolated footing alternatives (18 scenarios × 3 codes) and 36 raft alternatives (12 scenarios × 3 codes), totalling 90 code-specific alternatives Figure 1.

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Table 1. Base parametric matrix for isolated footing scenarios.

Base Case	Load Level	Soil Level	Soil qallow (kPa)	Column/layout
IF-01	L1	S1	100	400 x 400 mm column
IF-02	L1	S1	100	600 x 600 mm column
IF-03	L1	S2	200	400 x 400 mm column
IF-04	L1	S2	200	600 x 600 mm column
IF-05	L1	S3	300	400 x 400 mm column
IF-06	L1	S3	300	600 x 600 mm column
IF-07	L2	S1	100	400 x 400 mm column
IF-08	L2	S1	100	600 x 600 mm column
IF-09	L2	S2	200	400 x 400 mm column
IF-10	L2	S2	200	600 x 600 mm column
IF-11	L2	S3	300	400 x 400 mm column
IF-12	L2	S3	300	600 x 600 mm column
IF-13	L3	S1	100	400 x 400 mm column
IF-14	L3	S1	100	600 x 600 mm column
IF-15	L3	S2	200	400 x 400 mm column
IF-16	L3	S2	200	600 x 600 mm column
IF-17	L3	S3	300	400 x 400 mm column
IF-18	L3	S3	300	600 x 600 mm column

Table 2. Base parametric matrix for raft foundation scenarios.

Base Case	Layout	Load Level	Soil Level	Soil qallow (kPa)	Column/layout	Number of Columns
RF-01	R1	RL1	S1	100	R1 (3 x 3 columns)	9
RF-02	R1	RL1	S2	200	R1 (3 x 3 columns)	9
RF-03	R1	RL1	S3	300	R1 (3 x 3 columns)	9
RF-04	R1	RL2	S1	100	R1 (3 x 3 columns)	9
RF-05	R1	RL2	S2	200	R1 (3 x 3 columns)	9
RF-06	R1	RL2	S3	300	R1 (3 x 3 columns)	9
RF-07	R2	RL1	S1	100	R2 (4 x 4 columns)	16
RF-08	R2	RL1	S2	200	R2 (4 x 4 columns)	16
RF-09	R2	RL1	S3	300	R2 (4 x 4 columns)	16
RF-10	R2	RL2	S1	100	R2 (4 x 4 columns)	16
RF-11	R2	RL2	S2	200	R2 (4 x 4 columns)	16
RF-12	R2	RL2	S3	300	R2 (4 x 4 columns)	16

Parameter Justification

For isolated footings, service axial loads of 700, 1200, and 1700 kN represent the three design levels, while allowable soil bearing pressures of 100, 200, and 300 kPa represent weak, intermediate, and stronger support conditions. Column sizes are 400 × 400 mm and 600 × 600 mm. The raft layouts comprise 3 × 3 and 4 × 4 regular grids, both with 4 m column spacing; each layout is evaluated under two prescribed column-load levels and three soil classes.

As shown in Table 3, concrete and reinforcement grades, soil-category definitions, the baseline contact law, and mesh-refinement rules are specified consistently. This control permits comparisons to focus on design-code-dependent geometry and reinforcement while preserving a common numerical modeling basis.

Table 3. General design and ANSYS modeling assumptions.

Assumption	Adopted value	Purpose in the comparative design
Concrete grade	C25/30; modeling reference strength fck or f_c prime = 25 MPa	Maintained constant to isolate the effects of code provisions and foundation geometry.
Reinforcement grade	fy = 420 MPa; Es = 200,000 MPa	Used for all footing and raft reinforcement alternatives.
Soil levels	S1 = 100 kPa, S2 = 200 kPa, S3 = 300 kPa	Represents weak, medium, and strong service-level bearing conditions.
Loading	Static vertical concentric column loading	Selected to focus on code and SSI effects before eccentric or seismic branches are introduced.

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Interface	Hard contact in compression; separation allowed; baseline frictionless tangential behavior	Prevents nonphysical tensile resistance from the soil while keeping the main compression controlled.
Gravity	Off in the baseline ANSYS input	Avoids double counting because a 10% sizing allowance is already included in the design database.
Mesh refinement	Column region = t/4; general foundation = t/2; near-field soil = min(t/2, B_ref/8)	Refines the critical stress-gradient region while controlling model size.

Governing Calculation Expressions and Model-Input Transformations

Equations (1)-(12) express the design outputs and finite element inputs. Forces are stated in kN, plan dimensions in m, and stresses in kPa for service bearing calculations. Where surface pressures are entered in ANSYS using N and mm, they are expressed in MPa (N/mm^2); the applicable conversion factors are identified explicitly below.

(1) $P_s = D + L$

Service Axial Load

Here, D and L are the service dead and live axial loads (kN), respectively; P_s is the total unfactored axial force (kN) used for bearing-area sizing and for the service-load analysis branch.

(2) $Areq = \gamma_s P_s / qallow$

Required Bearing Area

In Eq. (2), Areq is the required foundation plan area (m^2), $\gamma_s = 1.10$ is the assumed allowance for foundation self-weight and associated effects, P_s is in kN, and qallow is the allowable soil pressure in kPa (kN/m^2).

(3) $\eta q = \gamma_s P_s / (Af\ qallow)$

Bearing Utilization Ratio

In Eq. (3), ηq denotes the dimensionless service bearing-utilization ratio, Af is the adopted plan area (m^2), and the remaining symbols are as defined for Eq. (2). The adopted sizing criterion is $\eta q \leq 1.0$.

(4) $Vc = Lf\ Bf\ t$

Concrete Volume

In Eq. (4), Lf and Bf are the plan length and width (m), t is foundation thickness (m), and Vc is the nominal concrete volume (m^3), excluding optional secondary construction allowances.

(5) $As,prov = (\pi\phi^2 / 4)(1000 / s)$

Provided Reinforcement Area Per Meter Width

Equation (5) converts the nominal area of one circular reinforcing bar into the area provided per metre width. Here, ϕ is bar diameter (mm), s is center-to-center spacing (mm), and As,prov is the provided steel area (mm^2/m).

(6) $Ws = As,prov\ Lf\ Bf\ n\ \rho s\ (1.10) \times 10^{-6}$

Steel Weight

In Eq. (6), Ws is reinforcement weight (kg), As,prov is in mm^2/m, Lf and Bf are in m, n is the number of reinforcement direction/layer sets (two for the adopted isolated-footing layout and four for the adopted raft layout), and $\rho s = 7850\ kg/m^3$. The factor 10^{-6} converts mm^2 to m^2; the factor 1.10 is the stipulated detailing allowance. This expression is a quantity-estimation convention, not a substitute for a bar-bending schedule.

(7) $pcol,s = 1000\ P_s / Acol$

Service Column-Face Pressure

The quantity pcol,s is the equivalent average service pressure applied over the column-stub top face (MPa = N/mm^2). P_s is in kN and Acol is the loaded column-top area in mm^2; multiplying by 1000 converts kN to N.

(8) $pcol,u = 1000\ P_u / Acol$

Ultimate Column-Face Pressure

Equation (8) defines the corresponding ultimate-load surface pressure in MPa for code-specific factored axial load P_u (kN), applied over the same column area Acol (mm^2).

(9) $Lsoil = Lf + 6Bref;\ \ Bsoil = Bf + 6Bref;\ \ Hsoil = 3Bref$

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Soil Domain Dimensions

In Eq. (9), Bref = min(Lf, Bf) is the smaller foundation plan dimension. The soil continuum extends by three Bref on each horizontal side of the foundation and to a depth of three Bref below the interface. Domain-size sensitivity remains necessary before interpreting calculated settlements.

(10) $\Delta S = S_{max} - S_{min}$

Differential Settlement

Here, Smax and Smin are the maximum and minimum vertical settlement magnitudes within the specified foundation measurement set. Their difference, ΔS, represents differential settlement and is evaluated only after obtaining displacement results from a completed finite element solution.

(11) $q_{avg} = P_s / A_f$; $q_{max} = \max(q_i)$

Contact Pressure Indicators

In Eq. (11), qavg is the nominal average pressure (kPa) obtained using P_s in kN and Af in m^2; qi denotes an individual computed compressive contact-pressure value, and qmax is its maximum over the contact interface. The qmax/qavg ratio is a pressure-concentration indicator obtainable after solution, whereas qavg is a pre-solution nominal reference.

(12) $\Delta X_{code}(\%) = 100(X_{code} - X_{ref}) / X_{ref}$

Percentage Difference

Equation (12) expresses the percentage difference in any response or material quantity Xcode relative to a clearly identified reference design Xref. Comparisons are valid when Xref is nonzero and both quantities share the same units.

ANSYS Nonlinear Finite Element Model Definition

The finite element model provides a common analysis environment rather than a fourth design standard. Each code specifies its own foundation dimensions and reinforcement, while the material-property definitions, soil-domain protocol, contact formulation, and meshing criteria remain consistent within matched comparisons. Concrete and soil are represented using compatible three-dimensional solid elements, with reinforcement represented by an appropriate embedded or discrete formulation. ANSYS documents SOLID65 as an archived reinforced-concrete element and identifies SOLID185 as a current-technology alternative; REINF264 provides a discrete reinforcement capability with compatible base elements [12-14,18]. As shown in Figure 2, the column stub transfers load across a finite face, and the soil top coincides with the foundation underside. The dimensions Lf, Bf, t, and Bref determine the foundation geometry and surrounding soil domain.

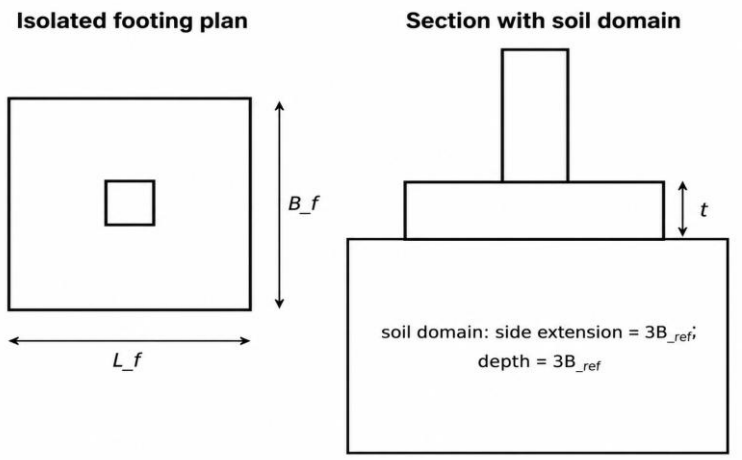


Figure 2. Isolated footing geometry, column stub, and surrounding soil domain used for ANSYS input.

As shown in Figure 3, the 3 × 3 and 4 × 4 raft layouts differ in loaded footprint and the number and relative positions of columns. These differences affect the geometric organization of potential local shear regions and global raft action and therefore must be preserved when constructing the matched finite element models.

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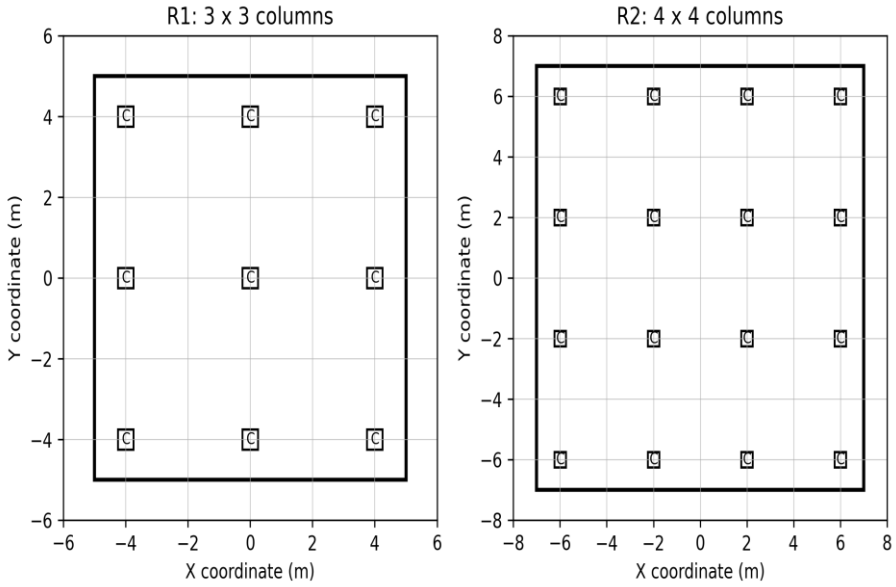


Figure 3. Raft foundation layouts used to generate multi-column ANSYS models.

As shown in Figure 4, separate material assignments are maintained for the concrete foundation, reinforcement, and soil body. The soil-foundation interface is defined to transfer compression without resisting tension across an open contact gap. This unilateral constraint permits separation and recontact and avoids an artificial tensile reaction from the supporting soil.

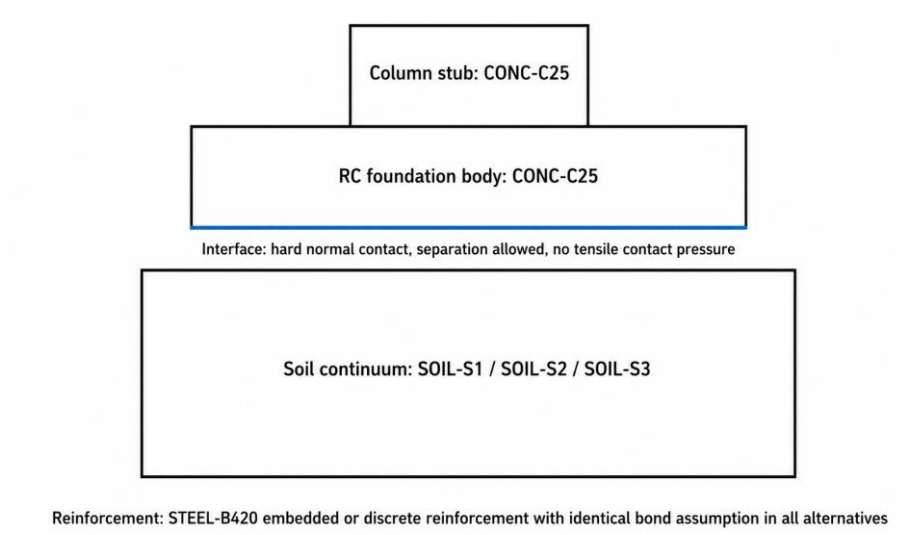


Figure 4. Material, reinforcement, soil, and contact assignment logic used in the ANSYS-ready models.

As shown in Table 4, the concrete and reinforcement material definitions are common to all designs, whereas the assigned soil material changes only with the prescribed soil level. The table also distinguishes current ANSYS element technology from the archived SOLID65 formulation, preventing the element-selection convention from being confused with measured material behavior.

Table 4. Material definitions and ANSYS assignment identifiers.

Material ID	Material Name	Assigned Bodies	Recommended Element Family	Elastic Modulus MPa	Poisson 's ratio	Yield / Compressive Strength MPa	Allowable Bearing kPa	Input / Calibration Note
CONC-C25	C25/30 reinforced concrete	Footing, raft, and column stub	Primary: SOLID185/SOLID186 with a compatible concrete model; legacy route: SOLID65	30000	0.2	25	-	Use one concrete model consistently in all 90 runs. If SOLID65 is used, it is an archived element and must be

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								identified as such.
STEEL-B420	Reinforcement steel B420	All footing and raft reinforcement	REINF264 or validated embedded/discrete reinforcement	200000	0.3	420	-	Yield strain = 0.00210. Perfect bond is assumed in the main matrix.
SOIL-S1	Weak linear-elastic soil	Soil body in S1 models	SOLID185/SOLID186 or equivalent structural solid	15	0.35	-	100	Density is not required because gravity is OFF. Use site-specific density only if gravity is later activated.
SOIL-S2	Medium linear-elastic soil	Soil body in S2 models	SOLID185/SOLID186 or equivalent structural solid	30	0.32	-	200	Density is not required because gravity is OFF.
SOIL-S3	Strong linear-elastic soil	Soil body in S3 models	SOLID185/SOLID186 or equivalent structural solid	60	0.3	-	300	Density is not required because gravity is OFF.

As shown in Table 5, column-center coordinates can be reused for all code alternatives within a given raft layout. The centered coordinate system makes the column type (corner, edge, or interior) explicit and supports repeatable geometric definition and local mesh refinement.

Table 5. Column-center coordinates used for raft foundation model creation.

Layout	Column Number	Grid Row	Grid Column	Column Centre X mm	Column Centre Y mm	Column Type
R1	1	1	1	-4000	-4000	Corner
R1	2	1	2	0	-4000	Edge
R1	3	1	3	4000	-4000	Corner
R1	4	2	1	-4000	0	Edge
R1	5	2	2	0	0	Interior
R1	6	2	3	4000	0	Edge
R1	7	3	1	-4000	4000	Corner
R1	8	3	2	0	4000	Edge
R1	9	3	3	4000	4000	Corner
R2	1	1	1	-6000	-6000	Corner
R2	2	1	2	-2000	-6000	Edge
R2	3	1	3	2000	-6000	Edge
R2	4	1	4	6000	-6000	Corner
R2	5	2	1	-6000	-2000	Edge
R2	6	2	2	-2000	-2000	Interior
R2	7	2	3	2000	-2000	Interior
R2	8	2	4	6000	-2000	Edge
R2	9	3	1	-6000	2000	Edge
R2	10	3	2	-2000	2000	Interior
R2	11	3	3	2000	2000	Interior
R2	12	3	4	6000	2000	Edge
R2	13	4	1	-6000	6000	Corner
R2	14	4	2	-2000	6000	Edge
R2	15	4	3	2000	6000	Edge
R2	16	4	4	6000	6000	Corner

Verification, Quality Control, and Model-Readiness Criteria

Before any nonlinear FE output is interpreted, the input records must satisfy dimensional, material, and quantity-consistency checks. Accordingly, bearing utilization, concrete volume, reinforcement area, and reinforcement weight were

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recalculated from the model-input schedules. These checks reduce the risk of data-transfer errors, but they do not establish experimental validation or the numerical accuracy of a future FE solution.
As shown in Table 6, the specified checks are separated into pre-solution input verification and post-solution numerical verification. Pre-solution checks address data integrity and geometry; post-solution checks address reaction equilibrium and contact state and must be performed on completed solution files.

Table 6. Verification and model-readiness protocol.

Check	Acceptance criterion	Reason for inclusion
Geometry check	Positive dimensions; soil domain larger than foundation; correct Z extents	Prevents missing bodies, inverted dimensions, or incorrect soil placement.
Material check	Concrete, steel, and selected soil material assigned to all relevant bodies	Prevents accidental use of wrong material properties across code alternatives.
Bearing check	ηq ≤ 1.0 for the adopted service area	Confirms that the selected plan satisfies the service bearing assumption.
Concrete-volume check	Spreadsheet volume equals L_f B_f t within rounding tolerance	Confirms that the reported concrete economy indicator is consistent with model geometry.
Steel-weight check	Reported steel weight agrees with bar diameter, spacing, layers, and density.	Confirms that reinforcement economy is calculated consistently.
Reaction check after solution	Summed support reaction approximately equals applied vertical load	Confirms global equilibrium after FE solution.
Contact-status check after solution.	Compression transfer with no tensile contact pressure	Confirms physically meaningful soil-foundation interaction.

Results

The results presented here describe the internally verified code-generated design database and the corresponding ANSYS-ready input specifications. They quantify differences in geometry, reinforcement quantities, material demand, and governing checks. The settlement, contact-pressure, stress/strain, and cracking indicators in Table 11 form the extraction protocol for subsequent nonlinear solution runs and are not reported as computed FE results in the present dataset.
As shown in Table 7, the mean isolated-footing thickness is smallest under ECP (397.22 mm), followed by ACI (441.67 mm) and EC2 (455.56 mm). Conversely, ECP yields the largest mean isolated-footing reinforcement weight (218.38 kg), compared with 182.91 kg for EC2 and 166.12 kg for ACI. For rafts, EC2 produces the greatest mean thickness (541.67 mm) and concrete volume (84.53 m^3), while ECP produces the largest mean reinforcement weight (10,509.7 kg). The results therefore distinguish concrete-related economy from reinforcement-related economy rather than combining them into a single measure of conservatism.

Table 7. Summary statistics for the 90 code-specific alternatives.

Foundation system	Code	Models	Mean t (mm)	Min t (mm)	Max t (mm)	Mean Vc (m3)	Mean steel (kg)	Mean shear U	Mean bearing U
Isolated footing	ACI	18	441.667	300	600	3.989	166.117	0.914	0.967
Isolated footing	EC2	18	455.556	300	600	3.982	182.911	0.881	0.967
Isolated footing	ECP	18	397.222	300	550	3.556	218.383	0.869	0.967
Raft foundation	ACI	12	458.333	400	550	71.767	8,342.6	0.888	0.601
Raft foundation	EC2	12	541.667	450	700	84.533	7,545.3	0.937	0.601
Raft foundation	ECP	12	425	400	450	66.8	10,509.7	0.798	0.601

As shown in Figure 5, the code ranking depends on foundation system. ECP produces the lowest average isolated-footing thickness, whereas EC2 yields the highest mean raft thickness. Thickness differences alter concrete volume and structural depth, but numerical performance implications cannot be established from thickness alone.

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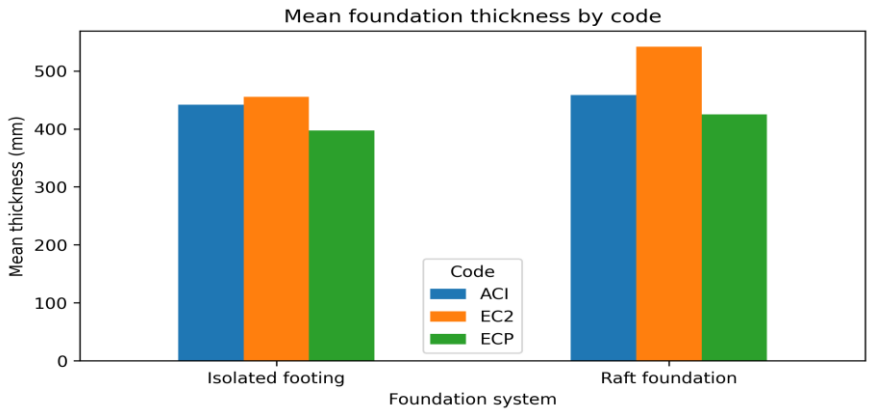


Figure 5. Mean foundation thickness by design code and foundation system.

As shown in Figure 6, the concrete volume reflects both plan dimensions and code-dependent thickness. Because the raft plans are substantially larger, relatively modest thickness changes produce more pronounced absolute differences in concrete volume than in individual footings.

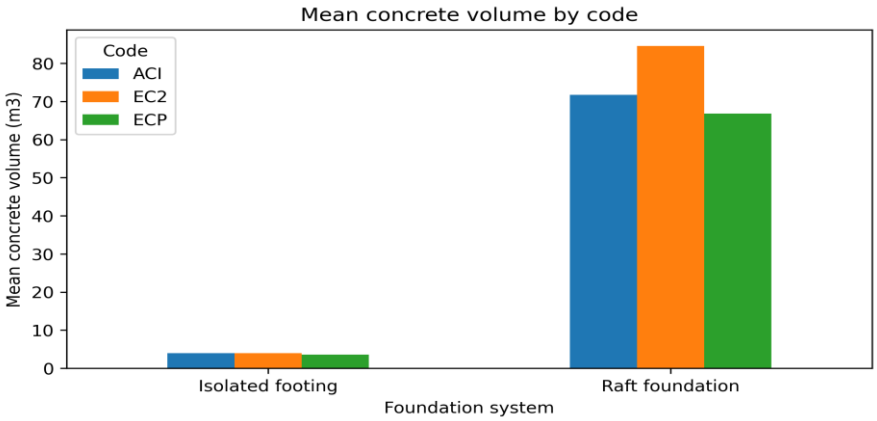


Figure 6. Mean concrete volume by design code and foundation system.

As shown in Figure 7, reinforcement consumption does not follow the same ranking as concrete volume. The code with the thinner foundation need not have the lowest reinforcement quantity, because bar diameter, spacing, layer count, and governing detailing requirements also determine total steel weight.

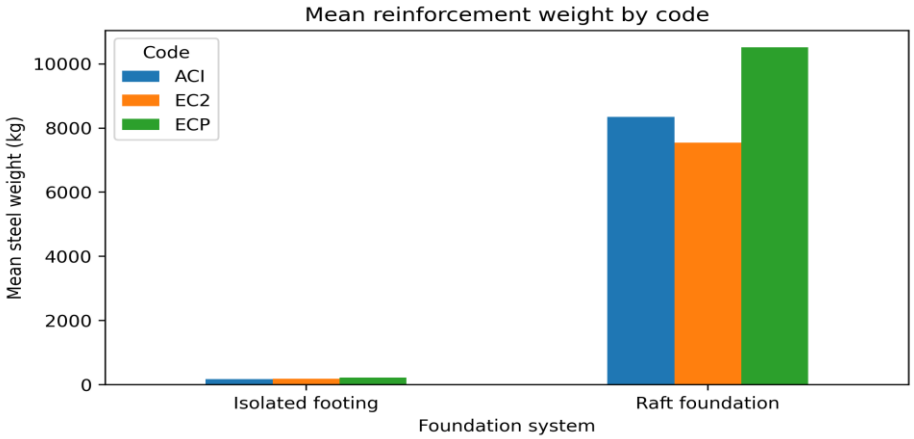


Figure 7. Mean reinforcement weight by design code and foundation system.

As shown in Table 8, differences among S1, S2, and S3 reflect changes in prescribed allowable soil pressure and associated foundation sizing. Isolated-footing plan area tends to decrease as soil bearing capacity increases, while raft geometry remains additionally constrained by its column layout. Thus, soil-related effects and code-related material effects should be interpreted separately.

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Table 8. Design-output trends by soil level and code.

Foundation system	Soil	Code	Mean t (mm)	Mean Vc (m3)	Mean steel (kg)	Mean bearing U
Isolated footing	S1	ACI	458.333	6.728	283.9	0.971
Isolated footing	S1	EC2	441.667	6.355	332.7	0.971
Isolated footing	S1	ECP	416.667	6.015	371.817	0.971
Isolated footing	S2	ACI	441.667	3.21	132.117	0.971
Isolated footing	S2	EC2	466.667	3.38	135.383	0.971
Isolated footing	S2	ECP	391.667	2.823	176.517	0.971
Isolated footing	S3	ACI	425	2.03	82.333	0.961
Isolated footing	S3	EC2	458.333	2.21	80.65	0.961
Isolated footing	S3	ECP	383.333	1.828	106.817	0.961
Raft foundation	S1	ACI	450	79.6	8,498.8	0.9
Raft foundation	S1	EC2	500	88.3	8,154.0	0.9
Raft foundation	S1	ECP	425	74.6	10,409.3	0.9
Raft foundation	S2	ACI	462.5	67.85	8,264.5	0.543
Raft foundation	S2	EC2	562.5	82.65	7,240.9	0.543
Raft foundation	S2	ECP	425	62.9	10,559.9	0.543
Raft foundation	S3	ACI	462.5	67.85	8,264.5	0.362
Raft foundation	S3	EC2	562.5	82.65	7,240.9	0.362
Raft foundation	S3	ECP	425	62.9	10,559.9	0.362

As shown in Figure 8, the bearing-utilization ratio describes how closely a selected foundation plan approaches the prescribed allowable-pressure criterion. Isolated footings are intentionally sized near this limit, whereas raft utilization changes more substantially with the fixed column-grid arrangement and selected raft dimensions.

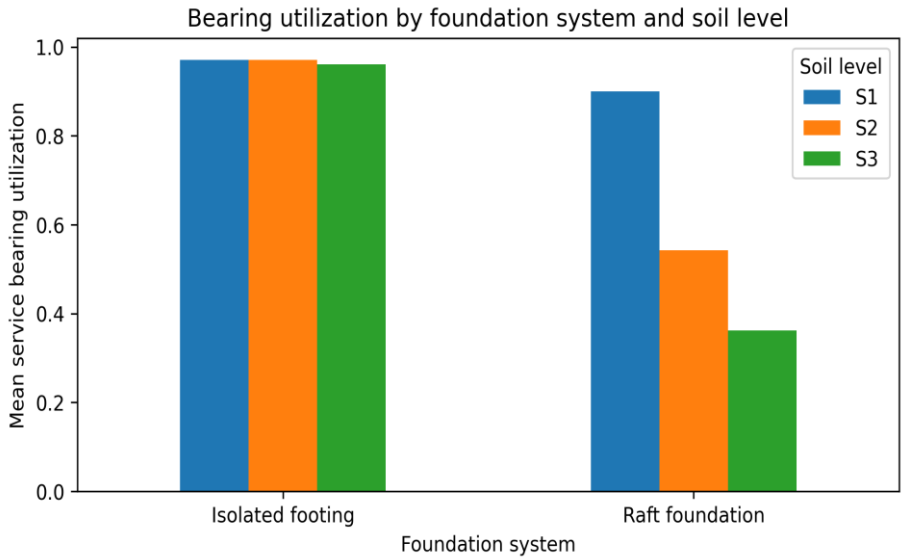


Figure 8. Mean service bearing utilization by soil level.

As shown in Figure 9, isolated-footing thickness varies jointly with loading, soil level, column dimensions, and the governing design code. The display retains all 54 isolated-footing designs, making it possible to identify matched-case differences without treating overall means as representative of every design.

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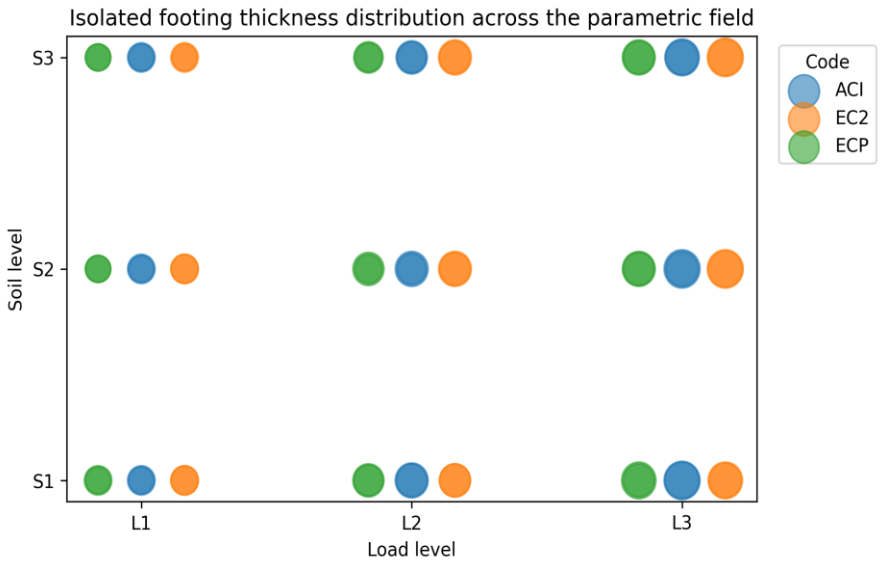


Figure 9. Isolated footing thickness field across load level, soil level, and design code.

As shown in Table 9, flexure governs the majority of the reported alternatives, while punching shear and one-way shear govern selected cases. The distribution is not evidence that a particular code is intrinsically safer: it identifies the checks that controlled the final dimensions and reinforcement within the adopted design procedures.

Table 9. Distribution of governing design checks.

Foundation System	Design Code	Flexure	One-way shear	Punching shear
Isolated footing	ACI	13	0	5
Isolated footing	EC2	15	2	1
Isolated footing	ECP	15	0	3
Raft foundation	ACI	12	0	0
Raft foundation	EC2	9	3	0
Raft foundation	ECP	12	0	0

As shown in Figure 10, the governing-check distributions vary with both code and foundation type. For isolated footings, punching shear is more frequent in the ACI and ECP alternatives than in the EC2 alternatives. In the raft subset, one-way shear governs three EC2 designs, while flexure governs the remaining raft alternatives.

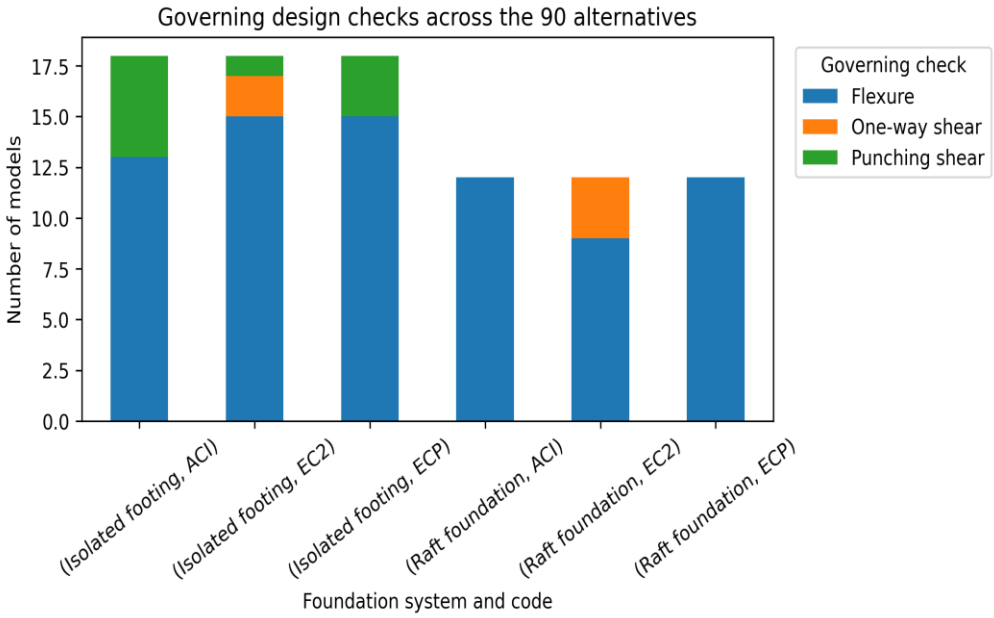


Figure 10. Stacked distribution of governing checks for each foundation system and code.

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As shown in Table 10, the displayed records illustrate the quality-assurance fields used to screen the 90 model inputs for geometric consistency, bearing adequacy, and reinforcement-quantity agreement. A PASS designation confirms the specified input checks only; it does not certify nonlinear FE performance.

Table 10. Representative rows from the independent quality-control register.

Model ID	Foundation System	Bearing Check	Volume Check	Steel Area Check	Weight Check	Overall QA
IF-01-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-01-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-01-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-02-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-02-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-02-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-03-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-03-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-03-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-04-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-04-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-04-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-05-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-05-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-05-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-06-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-06-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-06-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-07-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-07-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-07-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-08-ECP	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-08-ACI	Isolated Footing	PASS	PASS	PASS	PASS	PASS
IF-08-EC2	Isolated Footing	PASS	PASS	PASS	PASS	PASS

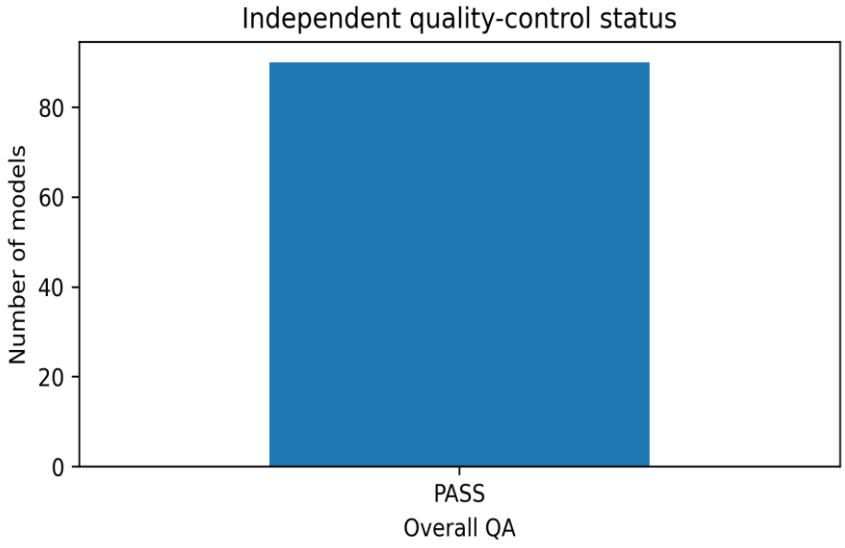


Figure 11. Overall independent quality-control status of the model database.

As shown in Figure 11, all listed design records pass the defined pre-solution consistency checks. This status supports the traceability of the model-input database but must not be interpreted as experimental validation or as proof of nonlinear FE convergence.

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Discussion

The findings demonstrate that code selection affects foundation design along multiple, non-equivalent dimensions. In the isolated-footing subset, ECP gives the lowest mean thickness but the highest mean reinforcement weight; ACI gives the lowest mean reinforcement weight, whereas EC2 gives the highest mean thickness. For raft foundations, EC2 leads in mean thickness and concrete volume, while ECP leads in mean reinforcement weight. These differences reflect the combined effects of code-specific load factors, resistance provisions, detailing requirements, and changes in final geometry. No single material quantity or mean utilization index can independently establish overall safety or economy. Rather, the results should be interpreted as design-output trade-offs within the prescribed parametric matrix.

The code-dependent variation in dimensions and reinforcement is consistent with the general comparison of actions and resistances by Bakhoum et al. [1] and the structural-geotechnical design perspective discussed by Abdrabbo et al. [2]. El-Said et al. [3] identified the sensitivity of footing punching predictions to effective depth, reinforcement ratio, and subsoil idealization, while Halvonik et al. [4] documented the role of support conditions in experimental comparisons. Bonić et al. [5] similarly emphasized soil-structure interaction in footing punching resistance. El-Naqeeb et al. [6] investigated biaxially eccentric punching behavior numerically, and Truong and Kim [7] considered soil-footing friction in punching resistance. These findings explain why the input database records geometry and interface conditions explicitly. For rafts, Saeed [8] showed that nonlinear soil assumptions can materially alter internal actions and pressure redistribution, while Amrane [9] demonstrated the influence of calibrated constitutive laws on settlement estimates for shallow footings. Ors et al. [10] investigated punching experimentally in footings resting on sand, and Yoon and Lee [11] used finite element interaction factors in foundation-settlement modeling. The current contribution differs from those studies in scope: it documents a controlled 90-design matrix and the complete input transformations for matched code-based comparisons. It does not, on the basis of the input database alone, claim experimentally validated settlement predictions or a nonlinear performance ranking.

The principal contribution is the integration of three steps: independent code-based foundation design, transformation of design outputs into consistent finite element model inputs, and quantitative comparison of design-stage material and limit-state indicators. Each design alternative is traceable from its base case to the resulting geometry, reinforcement schedule, material assignments, soil domain, load branches, and mesh criteria. This framework helps prevent inconsistencies when transferring independently designed sections into a common numerical environment. It also makes clear that ECP, ACI, and EC2 do not necessarily generate the same physical foundation for identical loading and soil conditions; subsequent FE comparisons should therefore evaluate the actual code-generated designs rather than isolated resistance equations.

As shown in Table 11, the listed outputs form a standardized extraction protocol for completed nonlinear analyses. Settlement, contact-pressure statistics, concrete and reinforcement stresses, reaction balance, and contact status would be extracted under the designated loading branches. These are planned response measures, not numerical results supplied by the present design database.

Table 11. Standardized nonlinear ANSYS result-extraction protocol.

Output variable	ANSYS extraction source	Branch	Interpretive purpose
Smax	Directional deformation in global Z	Service branch	Maximum service settlement and vertical stiffness response.
Delta S	Settlement probes at corner, edge, centre, and column-line points	Service branch	Differential settlement and distortion tendency.
qavg and qmax	Contact-pressure statistics at the soil-foundation interface	Service branch	Pressure redistribution and local concentration.
Load-settlement curve	Substep force-displacement output	Service and ultimate branches	Nonlinear stiffness degradation and convergence behavior.
Principal tensile stress/strain	Concrete stress/strain result objects	Ultimate branch	Cracking-prone regions and local tension zones.
Concrete compressive stress	Concrete stress result objects	Ultimate branch	Compressive stress concentration beneath column regions.
Reinforcement stress/strain	Reinforcement element or embedded rebar output	Ultimate branch	Yielding tendency and ductility demand.
Punching-related demand indicator	Column-region stress/strain concentration and critical perimeter probes	Ultimate branch	Comparative demand around loaded columns.
Reaction balance	Summed support reactions	All branches	Global equilibrium and numerical acceptance.
Contact status	Contact tool: open, closed, penetration, gap	All branches	Physical validity of soil-foundation interaction.

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Conclusions

Comprehensive Database

An internally verified, multi-code design and model-input database covering 90 alternatives (54 isolated footings and 36 rafts) was assembled. All cases have traceable geometry, reinforcement, soil-domain, material, contact, and mesh definitions suitable for constructing the corresponding ANSYS models.

Code Effects on Material Quantities

For isolated footings, ECP produced the lowest mean thickness (397.22 mm) but the highest mean reinforcement weight (218.38 kg); ACI produced a mean thickness of 441.67 mm and the lowest mean reinforcement weight (166.12 kg), while EC2 produced the greatest mean thickness (455.56 mm) and an intermediate mean reinforcement weight (182.91 kg). For raft foundations, EC2 produced the greatest mean thickness (541.67 mm) and concrete volume (84.53 m^3), whereas ECP produced the greatest mean reinforcement weight (10,509.7 kg).

Governing Limit State Distribution

Flexure governed 43 of the 54 isolated-footing designs and 33 of the 36 raft designs. Punching shear governed nine isolated-footing alternatives; one-way shear governed two isolated-footing and three raft alternatives, all associated with EC2 in the reported design matrix.

Design-to-Model Pipeline

The design-to-model database and the input tables presented in the Methods and Results sections provide a repeatable path from code-generated sections to finite element geometry, materials, reinforcement, boundary conditions, and output definitions.

Engineering Significance

The results show that code choice affects the foundation section supplied to the analysis model. Differences in thickness, reinforcement, and material quantities should therefore be compared within matched base scenarios, rather than inferred solely from design-code equations.

Future Research Foundation

The verified input records provide a starting point for service- and ultimate-load nonlinear analyses, mesh and contact sensitivity checks, and independent comparison against relevant experimental footing data.

Limitations and Future Work

The present study quantifies design-stage differences and documents the model-input framework; it does not report completed nonlinear FE response predictions. Further work should execute the planned service and ultimate load branches, verify mesh and soil-domain independence, assess contact-parameter sensitivity, introduce calibrated nonlinear soil constitutive models, and compare the numerical results against available footing tests. These extensions can retain the case identifiers and design matrix established here.

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Nomenclature

As shown in Figure 12, the research framework maps the progression from the parametric scenario matrix through three independently generated code designs to a common set of numerical-model inputs. Its purpose is to maintain traceability between code-induced design changes and the settings held constant for later response comparisons.

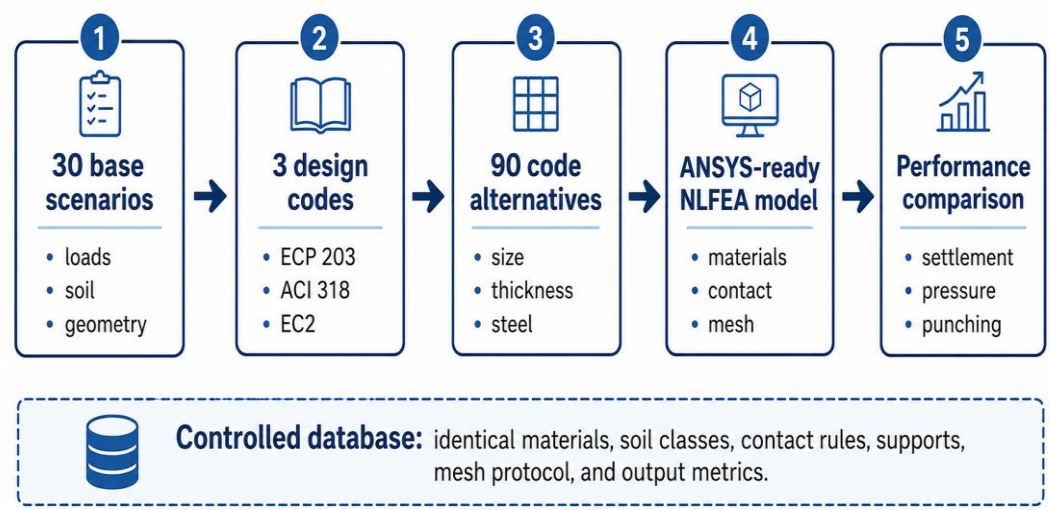


Figure 12. Graphical research framework linking the parametric matrix, code-based design, and ANSYS-ready nonlinear finite element assessment.

As shown in Table 12, the notation is defined consistently across the design calculations, ANSYS input database, and planned performance indicators. This prevents quantities expressed in different unit systems or technical contexts from being confused.

Table 12. Nomenclature and abbreviations used in the manuscript.

Symbol/abbreviation	Definition and use in the manuscript
ACI 318	Building Code Requirements for Structural Concrete, used as one of the three design standards.
ECP 203	Egyptian Code for Design and Construction of Reinforced Concrete Structures, used as the regional reference code.
EC2	Eurocode 2 EN 1992-1-1, used as the European design standard.
NLFEA	Nonlinear finite element analysis, used to capture material and contact nonlinearity after code-based design.
SSI	Soil-structure interaction, referring to the coupled response of foundation and supporting soil.
D, L	Dead and live axial load components acting on the column.
P_s, P_u	Service axial load and code-specific ultimate load.
q_{allow}	Allowable soil bearing pressure used for service-level plan sizing.
A_f	Foundation plan area resisting the service load.
ηq	Dimensionless service bearing-utilization ratio, ηq = 1.10 P_s/(Af qallow).
t	Foundation thickness controlling stiffness, punching resistance, and concrete volume.
$A_{s,prov}$	Provided reinforcement area per metre width (mm²/m), determined by bar diameter and spacing.
S_{max}, ΔS	Maximum settlement and differential settlement to be extracted from the ANSYS solution.
q_{avg}, q_{max}	Average and maximum contact-pressure indicators to be extracted from the soil-foundation interface.

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