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Tanque.NSR10: Computational Analysis and Design of Reinforced-Concrete Rectangular Liquid-Retaining Tanks under the Colombian Code NSR-10 and ACI 350.3

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Preprint in preparation for submission to EngrXiv. Not peer-reviewed. Software and verification suite available in a public repository (https://github.com/MauricioVictoriaN/Tanque.NSR10); the calculation core is distributed as an obfuscated binary for academic use (its source is available to reviewers upon request). Comments: hidratecsa@gmail.com.

Highlights

- Integrated static and seismic analysis and design of reinforced-concrete rectangular liquid-retaining tanks under NSR-10 (Título C), ACI 350.3 and the Portland Cement Association tabulated methods.
- Double-reading verification of the PCA manual coefficient tables: independent manual transcription plus OCR, corner symmetry and physical boundary constraints.
- Validation against the worked Example 1 of the PCA manual: moment coefficients, shears and service moments reproduced exactly; design differences fully explained by the NSR-10 vs. ACI 350 load and durability philosophies.
- Automated verification suite of 822 assertions and 144 unit tests, with zero-regression runs after every correction.
- Identification of the uniform-load nature of the seismic Case 7 tables and conservative extension of the tabulated domain with verified monotonicity.

Abstract

Background. Reinforced-concrete liquid-retaining structures require tedious calculations and the interpolation of design charts and tables – a frequent source of human errors with structural consequences. In the Colombian context, design is governed by the NSR-10 building code, whose Título C adopts ACI 350 for environmental structures, complemented seismically by ACI 350.3, with the Portland Cement Association (PCA) manual as the reference analysis tool.

Methods. The author presents `Tanque.NSR10`, a computational tool for the analysis and design of rectangular reinforced-concrete liquid-retaining tanks, developed in C#/.NET 8 with an Avalonia interface. It analyses walls, roof and base slabs and recommends thicknesses and reinforcement per NSR-10 Título C, ACI 350.3 and the PCA manual, combining bilinear interpolation of the Chapter 3 wall tables (staggered grid of fifteen $(b/a, c/a)$ combinations) with the Marcus corner combination, Housner's two-mass seismic method and the Mononobe–Okabe dynamic earth pressure, and completing the design with flexure, shear and service crack-control checks ($f_{s,\max}$, durability factor S_d).

Key Results. Verification relies on three complementary strategies: double reading of the PCA tables (manual transcription and OCR, with corner symmetries and physical constraints); an automated suite of 822 assertions and 144 unit tests; and exact reproduction of the worked Example 1 of the

PCA manual (coefficients, shears and service moments), with the observed differences in ultimate moments explained by the load and durability philosophies of each code. Two original contributions are reported: the identification of the uniform-load nature of the seismic Case 7 tables, and a conservative, monotonicity-justified extension of the tabulated domain.

Conclusions. `Tanque.NSR10` provides a verified, reproducible and norm-grounded tool for the analysis and design of rectangular liquid-retaining tanks, eliminating silent simplifications and documenting every domain degradation explicitly.

Keywords: reinforced concrete; liquid-retaining tanks; rectangular tanks; NSR-10; ACI 350.3; seismic design; Housner method; computational tool; verification; Colombia.

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1 Introduction

1.1 Context and Motivation

Reinforced concrete is generally the most economical material for the construction of water- and liquid-retaining structures and, when correctly designed and constructed, provides long service life and low maintenance costs. However, the structural design of these containers involves numerous tedious calculations and the use of extensive design charts and tables (PCA , 1998). In practice, the manual interpolation of such tables is a recurrent source of careless human errors that can be fatal to the design: a misread coefficient or a mistranscribed value directly translates into insufficient reinforcement in a critical structural element.

In the Colombian regulatory context, the structural design of liquid-retaining tanks is governed by the NSR-10 building code (AIS , 2010). Its Título C adopts, for structures in contact with liquids, the requirements of the American Concrete Institute standard ACI 350 (ACI , 2006a), while the seismic action on liquid-containing structures is evaluated following ACI 350.3 (ACI , 2006b). As the reference analysis method, the tabulated coefficients of the Portland Cement Association manual *Rectangular Concrete Tanks* (PCA , 1998) provide the bending moments and shears of walls and slabs under the relevant boundary and loading conditions. A computational tool that integrates these three normative sources – the Colombian code (governing the design), the US seismic standard (governing the seismic action) and the tabulated reference methods (providing the structural analysis) – is a practical necessity for reliable design.

1.2 Problem Statement

Beyond the tedium of manual calculation, two specific problems motivated this work. First, the analysis of rectangular tank walls requires the two-ratio $(b/a, c/a)$ tables of the PCA manual Chapter 3, whose staggered grid contains "holes" (combinations not tabulated) and whose interpolation is error-prone when performed by hand; the same applies to the seismic Case 7 tables. Second, the verification of computational implementations of such tables is often weak: legacy, manually-verified academic tools of this kind are not always accompanied by an automated, reproducible verification suite, which makes it difficult to catch isolated transcription or interpolation errors before they propagate into a design (see Section 1.3). This observation reinforced a governing principle of the project: *the norm is the only source of truth, and no silent hole is acceptable* – every simplification or domain degradation must be explicit and visible in the results.

1.3 State of the Art

Computer-aided design packages for reinforced-concrete tanks have been reported since the early 1990s. The RCTANK program (Chau and Lee , 1991) automated the analysis and design of rectangular and circular tanks under the British codes BS 5337 and BS 8110, and verified its results against manual design methods for four representative configurations. Commercial general- purpose structural software provides finite-element alternatives, but their application to the specific case of liquid-retaining walls with free-top/ fixed-base boundary conditions typically requires specialised modelling decisions. In the local academic context, thesis-based teaching tools for this class of problem have also been developed and used over the years, typically verified by manual spot-checking rather than by an automated, reproducible assertion suite – a common and reasonable practice for tools of their generation, but one that offers fewer guarantees against isolated transcription or domain-boundary errors going unnoticed. This observation – combined with the principle that the norm is the only source of truth – motivated the construction of a new tool with automated, reproducible verification built in from the outset.

1.4 Identified Gap

The reviewed tools share common limitations: (i) they are anchored in codes other than NSR-10 (e.g. BS 5337/BS 8110) or predate ACI 350.3; (ii) their verification relies on a small number of hand-checked examples without an automated, reproducible assertion suite; (iii) their seismic handling of rectangular walls either omits the out-of-domain configurations or degrades them silently; and (iv) they do not expose the normative sources of every value and formula. `Tanque.NSR10` addresses these gaps by providing a norm-grounded, verification-first tool with explicit domain handling.

1.5 Objectives and Contributions

The objectives of this work are: (O1) to develop a computational tool for the static and seismic analysis and design of rectangular reinforced-concrete liquid-retaining tanks under NSR-10 Título C, ACI 350.3 and the PCA manual methods; (O2) to verify the underlying coefficient tables by double reading (independent manual transcription and OCR, with physical and symmetry constraints); (O3) to validate the program against the worked Example 1 of the PCA manual; and (O4) to document, transparently, every simplification and limitation. The main contributions are the tool itself, its automated verification suite (822 assertions, 144 unit tests), and two technical findings of general interest: the uniform-load nature of the seismic Case 7 tables and the conservative domain extension with verified monotonicity (Sections 5 and 6).

2 Normative Framework and Reference Methods

2.1 NSR-10 Título C and the adoption of ACI 350

The Colombian NSR-10 code (AIS , 2010) adopts, in Título C, the requirements of ACI 350 for concrete structures in contact with liquids. The sections implemented in `Tanque.NSR10` are: cover requirements (C.23-C.7.7.1); minimum shrinkage-and-temperature reinforcement as a function of the distance between movement joints, per direction (C.23-C.7.12.2.1); minimum wall reinforcement (C.23-C.14.3); maximum service steel stress and crack-control distribution (C.23-C.10.6.4.1, equations C.23-2/C.23-3); the crack-control coefficient β (equation C.23-4); the environmental durability factor $S_d = \varphi\, f_y/(\gamma\, f_s) \geq 1.0$ (equation C.23-1, section C.23-C.9.2.6); and the load combinations of section B.2.4.

The design load combinations used are:

$$U = 1.4\,(D + F) \qquad \text{(B.2.4-1, fluid-governed interior)} \tag{1}$$

$$U = 1.2\,(D + F) + 1.6\,(L + H) + 0.5\,(L_r \text{ or } S \text{ or } R) \qquad \text{(B.2.4-2, earth-governed exterior)} \tag{2}$$

$$U = 1.2\,(D + F) + 1.0\,E + 0.5\,(L_r \text{ or } S \text{ or } R) \qquad \text{(B.2.4-5, seismic, interior)} \tag{3}$$

$$U = 1.2\,(D + F) + 1.6\,H + 1.0\,E \qquad \text{(B.2.4-7, seismic, exterior)} \tag{4}$$

where F is the fluid pressure, H the earth pressure and E the seismic action. In the implemented wall analysis the interior seismic envelope is $1.2\,P_h + E$ and the exterior one is $1.6\,P_{s2} + Q_{ae}$, with P_h the hydrostatic base pressure, P_{s2} the Rankine soil base pressure and Q_{ae} the dynamic (seismic) earth pressure increment.

2.2 ACI 350.3-06: seismic design of liquid-containing structures

The seismic action follows ACI 350.3 (ACI , 2006b). The impulsive and convective forces are computed with Housner's two-mass idealisation:

$$P_w = C_i\,I\,(\varepsilon\,W_w/R_i), \qquad P_r = C_i\,I\,(W_r/R_i), \qquad P_i = C_i\,I\,(W_i/R_i), \qquad P_c = C_c\,I\,(W_c/R_c), \tag{5}$$

where P_w, P_r, P_i and P_c are the wall-inertia, roof, impulsive and convective forces (equations 4-1a/4-2/4-4 of ACI 350.3). The total base shear is combined by the square-root-sum-of-the-squares (SRSS) method as

$$V = \sqrt{(P_i + P_w + P_r)^2 + P_c^2 + P_{eg}^2} \qquad \text{(ACI 350.3, Eq. 4-5)}, \tag{6}$$

and the corresponding base moment as

$$M_b = \sqrt{(M_i + M_w + M_r)^2 + M_c^2} \qquad \text{(ACI 350.3, Eq. 4-10)}. \tag{7}$$

Section 3.3.3 of ACI 350.3 confirms that horizontal and vertical acceleration effects shall be combined by SRSS. Both equations were verified against the primary document text (page 350.3-16). In `Tanque.NSR10`, the SRSS principle is applied at the level of the base *pressures* of the impulsive and convective components,

$$E_{\text{int}} = \sqrt{p_i^2 + p_c^2}, \tag{8}$$

an analogy explicitly documented in the code (the wall panel analysis accepts a single design pressure profile); the wall-inertia and roof forces P_w and P_r belong to the global base shear of Eq. (4-5) and are deliberately excluded from the local panel flexure. For the exterior (buried) condition, $P_i = P_c = 0$ and the SRSS reduces to $E_{\text{ext}} = Q_{ae}$, the dynamic earth pressure increment computed with the Mononobe–Okabe method (Mononobe , 1929; Okabe , 1926) with the dynamic increment idealised after Seed and Whitman (1970).

2.3 PCA manual methods

The reference analysis methods are those of the PCA manual *Rectangular Concrete Tanks* (PCA , 1998). Two families of tables are used:

2.3.1 Chapter 2: Plate Analysis Results (Case 10)

For the roof and base slabs, the Case 10 tables (four edges hinged, uniform load) provide moment coefficients for ten span ratios $r = b/a$ from 0.5 to 4.0, with bilinear interpolation between tabulated values. The plates are analysed with the Marcus corner combination applied to the torsion moments (Section 3.3).

2.3.2 Chapter 3: Tank Analysis Results (Case 3 and Case 7)

For the walls, the Chapter 3 "Tank Analysis Results" provide coefficients for the free-top/fixed-base condition on a *staggered* grid of fifteen $(b/a,\ c/a)$ combinations with $b/a \in \{4,\ 3,\ 2,\ 1.5,\ 1\}$ and $c/a < b/a$. Each combination provides, for the long side (M_x, M_y, M_{xy}) and the short side (M_z, M_y, M_{yz}), the vertical, horizontal and torsional moments over an 11×6 field.

Two cases are used: the static Case 3 (triangular load, hydrostatic pressure) and the seismic Case 7. A finding of this work is that the **Case 7 tables are of uniform load**, not triangular: the base moments reach 0.43–$0.45\, q\, a^2$, which is physically impossible for a triangular load (whose one-way cantilever limit is $q\, a^2/6 = 0.167\, q\, a^2$, and plate action can only reduce it); the maximum tabulated deflection ($C_d \approx 101$) also exceeds the triangular cantilever limit ($C_d \approx 66.7$). The tables were verified against the original manual pages (3-67 to 3-74). Consequently, `Tanque.NSR10` feeds the seismic tables with the design base pressure applied uniformly, which constitutes a conservative envelope of the actual trapezoidal seismic pressure (Section 3.6).

2.4 Classic methods

The following classic methods are implemented and cited: Rankine active earth pressure (Rankine , 1857), Housner's two-mass hydrodynamic model (Housner , 1963), the Mononobe–Okabe dynamic earth pressure (Mononobe , 1929; Okabe , 1926), the Seed–Whitman dynamic increment idealisation (Seed and Whitman , 1970), and the Marcus corner moment combination (Marcus , 1932) as presented in the PCA manual.

3 Methodology

3.1 Dimensional conventions

Three consistent dimensional conventions are used throughout, according to the physical quantity: (i) flexure of walls and slabs uses the centre-to-centre span ($L - e_m,\ B - e_m$); (ii) the Housner liquid mass uses the clear interior span ($L - 2e_m,\ B - 2e_m$); and (iii) weights and distributed loads use the exterior dimensions ($B \times L$). These conventions were the subject of a dedicated correction campaign documented in the project's work log.

3.2 Loads and pressures

The interior liquid pressure is triangular with base value

$$P_h = \gamma_\ell\, H_L, \tag{9}$$

where γ_ℓ is the liquid unit weight and H_L the liquid height. The exterior soil pressure follows Rankine's theory with

$$K_a = \tan^2(45^\circ - \varphi/2)\,, \qquad P_{s2} = K_a\,\gamma_s\,H_m, \tag{10}$$

where φ is the soil friction angle, γ_s the soil unit weight and H_m the soil height (conservatively taken as the full wall height when specified). Surcharges and live loads are combined per section B.2.4.

3.3 Wall analysis

Wall panels are analysed with the Chapter 3 tables indexed by $(b/a,\, c/a)$. The interpolation is bilinear over the staggered grid, with exact values at the fifteen tabulated combinations. The corner torsion is combined with the Marcus method:

$$M_x^+ = \max(0,\, M_x + M_{xy}), \qquad M_x^- = \min(0,\, M_x - M_{xy}), \tag{11}$$

and analogously for the horizontal and short-side components. The wall shear is obtained from the Chapter 2 shear coefficients C_s, interpolated with the wall's own ratio $r = \text{span}/a$, which are valid directly without corner redistribution (PCA , 1998). The moment scale is $M = \text{Coef} \times q\,a^2/1000$ for the design pressure q and wall height a.

3.4 Plate analysis

The roof and base slabs are analysed with the Chapter 2 Case 10 tables (four edges hinged, uniform load) on their quarter panels, with the same Marcus corner combination. The roof slab uses the inverted convention ($a = L - e_m$, $b = B - e_m$, $r = b/a = B/L$) and the base slab the standard one ($a = B - e_m$, $b = L - e_m$, $r = b/a = L/B$); both are equivalent through the symmetry of the Case 10 tables.

3.5 Seismic action

The seismic interior envelope combines the impulsive and convective base pressures by SRSS ((8)) and adds them to the hydrostatic term:

$$q_{\text{int}} = 1.2\,P_h + \sqrt{p_i^2 + p_c^2} \qquad \text{(B.2.4-5)}. \tag{12}$$

The seismic exterior envelope combines the Rankine soil pressure and the dynamic earth increment:

$$q_{\text{ext}} = 1.6\,P_{s2} + Q_{ae} \qquad \text{(B.2.4-7)}. \tag{13}$$

The hydrodynamic pressures $p_i(y)$ and $p_c(y)$ follow the Housner trapezoidal distributions with the period, coefficient and height relations of ACI 350.3. The dynamic earth increment is $Q_{ae} = \gamma_s\,H_m\,(K_{ae} - K_a)$ from the Mononobe–Okabe analysis. The seismic actions are applied to the Case 7 (uniform-load) wall tables and combined cell-by-cell with the static envelope.

3.6 Design engine (NSR-10 Título C)

3.6.1 Flexure

Flexural reinforcement is dimensioned for the governing factored moment with the strength reduction factor $\varphi = 0.9$. The reinforcement ratio is bounded by the maximum ratio $\rho_{\max}$ (tension-controlled section) and by the governing minimum: the environmental shrinkage-and-temperature minimum of C.23-C.7.12.2.1 as a function of the joint spacing (≥ 0.0030 for $f_y = 420$ MPa), which governs structural slabs (C.10.5.4 remits slabs of uniform thickness to C.7.12), and the wall minimum of C.23-C.14.3 (0.0030 vertical). If the required ratio exceeds $\rho_{\max}$, an explicit "insufficient thickness" exception is raised – no silent acceptance.

3.6.2 Shear

The factored shear is compared with the concrete shear capacity φV_c per Título C; the shear coefficients C_s of the PCA Chapter 2 tables are used. Transverse (stirrup) reinforcement design is deliberately out of scope and documented as such.

3.6.3 Crack control and durability

Serviceability is checked at the service level: the service steel stress must satisfy the maximum value of equation C.23-2,

$$f_{s,\max} = \frac{57000}{\beta\,\sqrt{s^2 + 4\,(50 + d_b/2)^2}} \qquad \text{(MPa, } s \text{ and } d_b \text{ in mm)}, \tag{14}$$

capped at 250 MPa with floors of 140 MPa (one-way) and 170 MPa (two-way) per C.23-C.10.6.4.1, with β from equation C.23-4 (1.35 for $h < 400$ mm, 1.2 otherwise). In addition, the environmental durability factor of equation C.23-1,

$$S_d = \frac{\varphi\, f_y}{\gamma\, f_s} \geq 1.0, \qquad \text{(C.23-C.9.2.6)} \tag{15}$$

is applied at the service level. It is worth noting the difference with the ACI 350 "sanitary coefficient" of 1.3, which the PCA manual Example 1 applies by inflating the ultimate moment: NSR-10 implements durability at the service level without inflating M_u, and `Tanque.NSR10` follows NSR-10 (see Section 6.3).

3.6.4 Reinforcement catalogue

Reinforcement is selected from a commercial catalogue (No. 4 to No. 10, excluding No. 3 per C.23-C.7.12.2.2), with per-element diameter shielding and the underside-on-soil adjustment (50% of the reinforcement in the bottom 300 mm layer).

3.7 Domain handling of the seismic wall tables

Outside the tabulated domain of the Case 7 tables, the program computes a conservative one-way envelope (free-top/fixed-base cantilever plus horizontal strip) with explicit marking of the result as a conservative approximation:

$$M_x = q\,a^2/2 \quad \text{(uniform-load cantilever, a rigorous upper bound for any pressure } \leq q), \tag{16}$$

$$M_y = q\,L^2/8 \quad \text{(simply supported horizontal strip)}, \qquad V_{\text{base}} = q\,a/2, \quad V_{\text{side}} = q\,L/2. \tag{17}$$

For the intermediate band $1.0 \leq b/a < 2.0$, the one-way bounds are refined with the tabulated values of the $b/a = 3.0$ row at the panel's own c/a (taking the minimum with the strip, so the refinement never loosens the previous envelope). This is justified by the numerically verified monotonicity of the vertical and corner horizontal moments with respect to b/a and c/a over the fifteen tabulated combinations. The historical bound $M_x = q\,a^2/6$ (triangular cantilever) was found to be *not conservative* with respect to the uniform-load tables at the domain edge (0.167 vs. 0.43–$0.45\,q\,a^2$ at $b/a = 4.0$) and was corrected to

(16); the shear bound is kept at $q\,a/2$, consistent with the triangular C_s convention reused from the static tables.

4 Software Implementation

4.1 Architecture

`Tanque.NSR10` is implemented in C# on .NET 8 and organised into five projects: a calculation core of sixteen modules (`Tanque.Core`); a reporting project (`Tanque.Reportes`) generating text, HTML and CSV outputs; an Avalonia graphical application (`Tanque.App`); an xUnit test project (`Tanque.Core.Tests`, 144 tests); and a dedicated verification tool (`Tanque.Core.Verificacion`, 822 assertions). A facade (`CalculadorTanque`) orchestrates the modules, and JSON persistence (`PersistenciaTanque`) stores projects and parameters in a readable format. A geometric-guidance module (`SugerenciasGeometricas`) produces actionable messages when the tank aspect ratios fall outside the tabulated ranges, as shown in Figure 1.

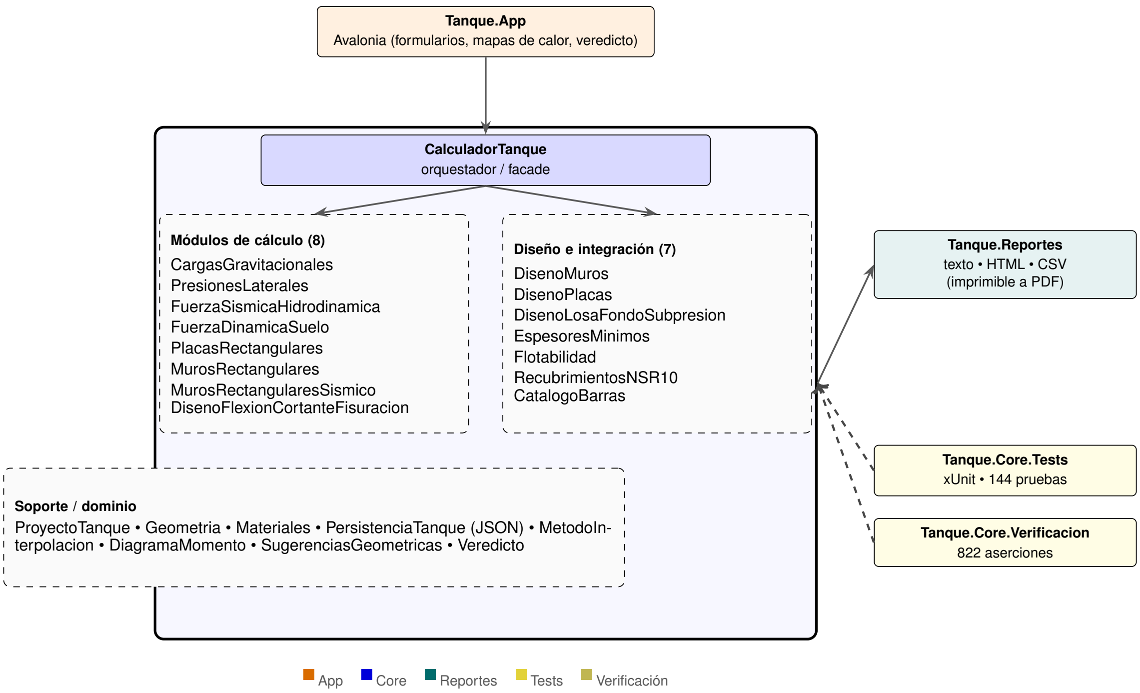

Figure 1: Architecture of `Tanque.NSR10`: five projects; the calculation core `Tanque.Core` exposes a facade (`CalculadorTanque`) that orchestrates eight calculation modules, seven design/integration modules and the support/domain layer (including `PersistenciaTanque` JSON persistence and the geometric-guidance `SugerenciasGeometricas`).

4.2 Graphical interface and reports

The Avalonia interface provides validated input forms (Formularios 7–11), oriented moment-diagram heat maps with a zero anchor, edge labels and the governing cell highlighted, and a global pass/fail verdict. Reports are generated as professional text, HTML (printable to PDF) and CSV exports. (Figure 2; the moment heat map of Figure 3 is computed directly from the program data).

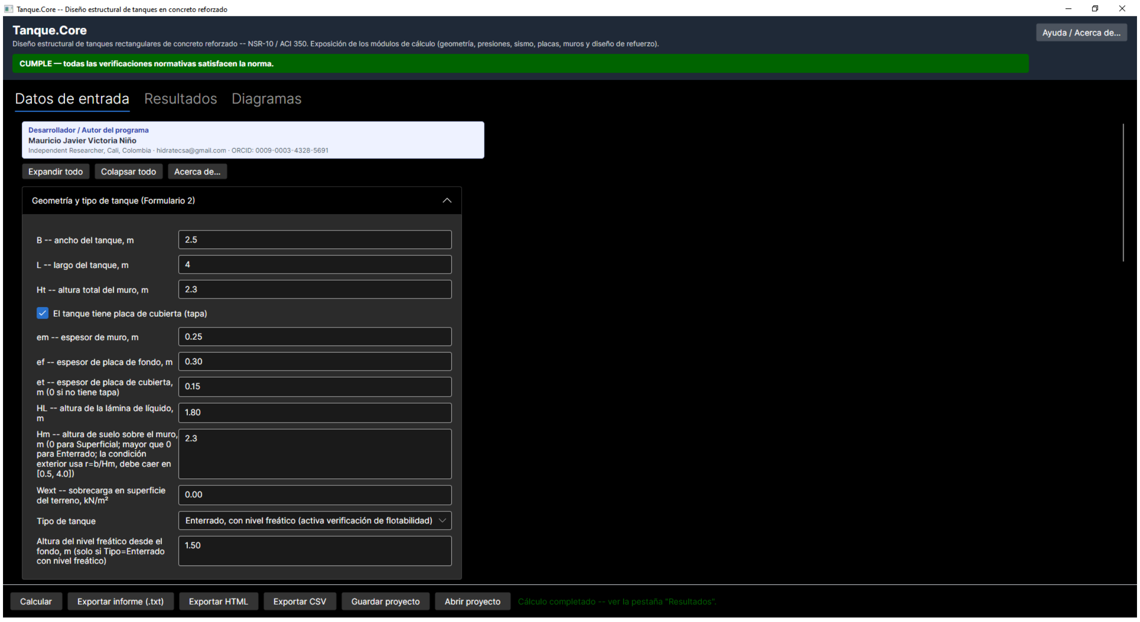

Figure 2: Screenshot of the Avalonia graphical interface of `Tanque.NSR10`: validated input forms (left), governing results (right), global pass/fail verdict and the report/export actions.

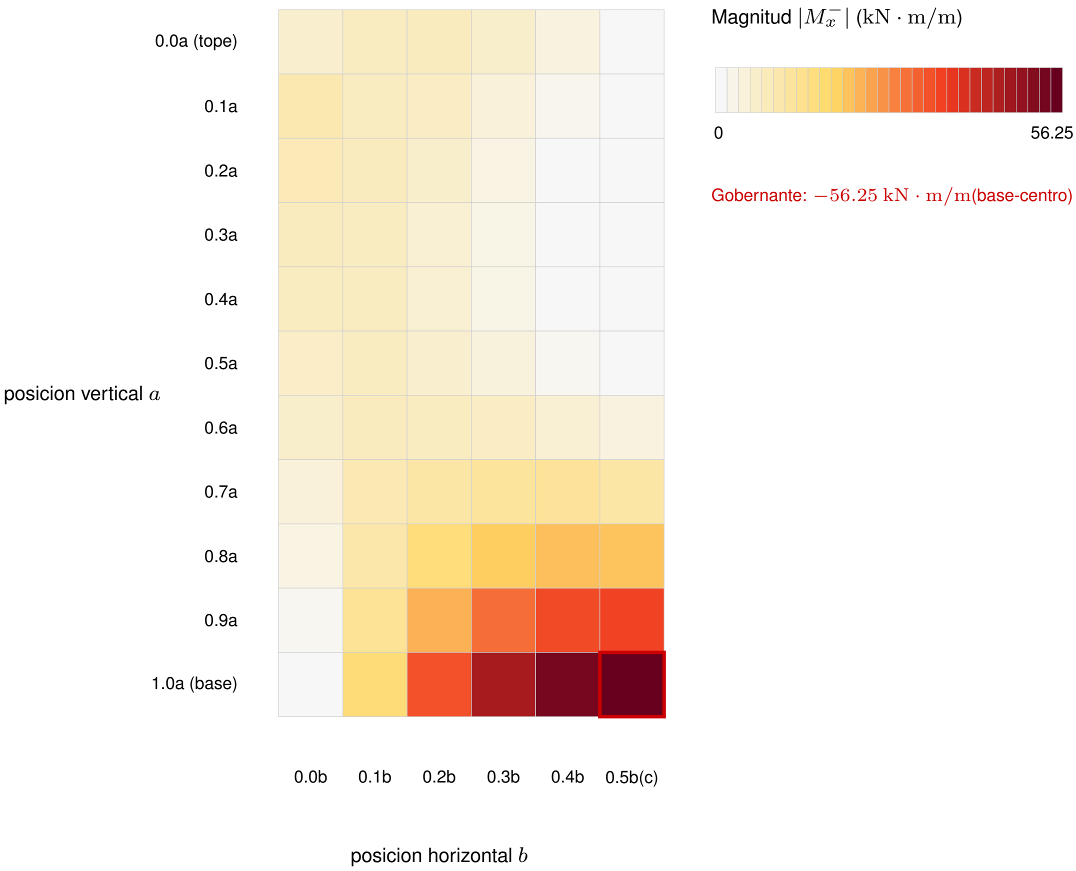

Figure 3: Moment heat map computed by `Tanque.NSR10` for the longitudinal wall, interior condition: M_x^- field $(\mathrm{kN \cdot m/m})$ on the 11×6 grid of the PCA/Marcus Case 3. The governing cell (base-centre, $-56.25\,\mathrm{kN \cdot m/m}$) is highlighted and the zero anchor is shown.

4.3 Verification infrastructure

The verification tool executes 822 assertions that recompute the closed-form formulae independently (force and moment equilibrium by hand integration), check the interpolation consistency at the domain limits ($b/a = 1.0$ and 4.0), verify the monotonicity of the grids, exercise every regime of the conservative envelope, and confirm the SRSS combination and the load factors. The 144 unit tests mirror the modules (loads, plates, walls, seismic, design, flotation, reports, geometry, persistence).

4.4 Reproducible table extraction

The PCA manual tables were extracted with a double-reading workflow: an independent manual transcription of every page and an OCR pipeline (tesseract.js) with pixel-level sign detection, rendered pages at 200–800 dpi. Corner symmetry ($M_{y,\text{long}} = M_{y,\text{short}}$, $M_{xy,\text{long}} = M_{yz,\text{short}}$) and physical constraints (zero torsion at the fixed base; zero vertical moment at the free top) were verified on every table, and a small number of transcription errors were corrected (e.g. cell $(3, 2)$, long side, BOT row, M_y at $0.5b$: -26 instead of 1). The confirmed data are stored as embedded coefficient matrices and as JSON files with page provenance. The OCR tooling is reproducible (`tools/OCR_PCA/`).

5 Verification

5.1 Double reading of the coefficient tables

Each of the fifteen $(b/a, c/a)$ combinations of Chapter 3 (Cases 3 and 7) was verified by two independent readings (manual transcription and OCR), plus corner symmetry and physical boundary constraints. The anchor values were confirmed against the original manual pages; for example, Case 3 $(3, 2)$: M_x at the base centre -129 (thousandths), M_y at the free top $[-55,\ -20,\ 9,\ 20,\ 23,\ 24]$; Case 7 $(3, 2)$: M_x at the base centre -359.

5.2 Automated assertions

The 822 assertions include: closed-form recalculation of the conservative bounds ($M_x = q\,a^2/2$ vs. the tabulated values at $b/a = 4.0$), consistency at the domain limits, monotonicity of the grids, the seismic SRSS structure and load factors (NSR-10 B.2.4-1/2/5/7), the crack-control equations (C.23-1/2/4) and the minimum reinforcement per C.23-C.7.12.2.1. All assertions pass (822/822); the 144 unit tests pass (144/144); the solution builds with zero warnings and zero errors.

5.3 Validation against the PCA manual Example 1

The program was run with the geometry of the worked Example 1 of the PCA manual: a rectangular tank 30×20 ft on centre lines, 10 ft liquid height, 18 in walls, $f'_c = 4000$ psi and $f_y = 60$ ksi. The geometry maps exactly onto the tabulated combination $(b/a,\ c/a) = (3.0,\ 2.0)$ of Case 3, so no interpolation is involved. The comparison shows:

- **Identical analysis:** the 16 governing moment values and the 1056 diagram cells (11×6 fields, 16 tables) coincide with the tabulated coefficients scaled by $q\,a^2/1000$; the shear coefficients C_s coincide ($0.50/0.37/0.24$ long side; $0.45/0.27/0.26$ short side); the service moments coincide (e.g. M_x at the base centre, coefficient -129, gives -108.4 in-kips/ft $= -40.18\ \mathrm{kN \cdot m/m}$).
- **Design differences fully explained:** the ultimate vertical moment at the base centre is -239.9 in-kips in the manual (ACI 350: $1.3 \times 1.7 = 2.21$ times the service value) versus -151.8 in-kips

in `Tanque.NSR10` (NSR-10: $1.4\,F$), a ratio of $2.21/1.4 = 1.58$; and the horizontal corner moment uses the Marcus combination ($M_y - M_{xy} = -83$ vs. the raw -78). Both differences are deliberate and consistent with the governing code.

5.4 Regression

The final release run of the example produces a report identical to the previous version except for the generation timestamp (zero regression after the domain corrections), confirming the determinism of the tool.

6 Results and Discussion

6.1 Worked example results

The governing values of the Example 1 run are summarised in Table 1. All serviceability checks pass ($f_s \leq f_{s,\max}$, $S_d \geq 1.0$), the minimum wall thickness check passes (0.457 m ≥ 0.30 m per C.23-C.14.6.2), and the flotation and seismic sections are correctly reported as omitted when not applicable. The analysis is identical to the manual's (16/16 governing moments, $1\,056$ diagram cells and identical shear coefficients), while the *ultimate* design moments differ by the governing code factor (NSR-10 $1.4\,F$ fluid / $1.6\,H$ soil versus ACI 350 $1.3 \times 1.7 = 2.21$), a ratio of $2.21/1.4 = 1.58$. Table 2 summarises the automated verification suite.

Table 1: Governing moments of the worked PCA Example 1 (tank 30×20 ft axis-to-axis, water 10 ft, walls $18''$, $b/a = 3.0$, $c/a = 2.0$). M_u are the NSR-10 factored design moments and $M_s^{\max}$ the governing service moment (values in $\mathrm{kN \cdot m/m}$).

Element	M_x^+	M_x^-	M_y^+	M_y^-	$M_s^{\max}$
Roof slab	30.34	29.00	29.00	29.00	22.26
Base slab	140.85	88.48	92.09	88.48	100.61
Long wall	10.90	56.25	14.39	36.20	40.18
Transverse wall	10.03	35.76	12.21	36.20	25.54

Table 2: Summary of the automated verification suite of `Tanque.NSR10` (all checks pass).

Verification component	Result
Automated assertion suite (`Tanque.Core.Verificacion`)	$822/822$ pass
Unit tests (`Tanque.Core.Tests`, xUnit)	$144/144$ pass
Compiled .NET projects	5 (0 errors, 0 warnings)
Coefficient tables (double-read, page provenance)	15 $(b/a, c/a)$ combos confirmed
Case 7 seismic tables cross-checked (pp. 3-67–3-74)	Uniform load; bound $M_x = q\,a^2/2$ verified
Governing moments vs. PCA manual Example 1	$16/16$ coincide; $1\,056$ cells reproduced
Transcription/interpolation errors	Corrected and documented (Section 5, Appendix S2)

6.2 Original findings

6.2.1 Uniform-load nature of the Case 7 tables

As described in Section 2.3, the seismic Case 7 tables are of uniform load. This finding changes the interpretation of the seismic wall results: feeding the base design pressure as a uniform load constitutes a conservative envelope of the actual trapezoidal seismic pressure (maximal at the base, decreasing towards the free top in the cases examined).

6.2.2 Correction of the conservative bound

The previous out-of-domain bound $M_x = q\,a^2/6$ was non-conservative and discontinuous at the domain edge: a wall barely wider than $b/a = 4.0$ would have been designed with $0.167\,q\,a^2$ while the tabulated edge value is 0.43–$0.45\,q\,a^2$. The corrected bound $M_x = q\,a^2/2$ ((16)) is a rigorous upper bound for any lateral pressure $\leq q$ and is verified against the tabulated values at $b/a = 4.0$ in the assertion suite.

6.2.3 Conservative domain extension

The intermediate band $1.0 \leq b/a < 2.0$ is refined with the tabulated row $b/a = 3.0$ (which covers every $c/a < 2.0$ of the band), taking the minimum with the one-way strip. The refinement never loosens the previous envelope and is justified by the verified monotonicity of the vertical and corner horizontal moments in b/a and c/a over the grid.

6.3 Comparison with the manual's design philosophy

The differences between `Tanque.NSR10` and the PCA manual Example 1 in the *ultimate* moments (ratio 1.58) are not discrepancies of the analysis but consequences of the governing codes: ACI 350 applies a sanitary coefficient of 1.3 by inflating M_u (total $1.3 \times 1.7 = 2.21$), while NSR-10 performs the durability check at the service level ($f_s \leq f_{s,\max}$, $S_d \geq 1.0$) without inflating M_u (factor $1.4\,F$). The Marcus corner combination used by `Tanque.NSR10` for the walls is the more complete treatment (the manual's example uses raw coefficients for walls but applies the Marcus combination to the roof slab, as does `Tanque.NSR10`).

6.4 Limitations

The following limitations are declared transparently: (i) the wall-inertia and roof forces P_w and P_r are excluded from the local panel pressure (they belong to the global base shear of Eq. 4-5) – a documented analogy, not a literal application; (ii) the SRSS is applied at the base-pressure level rather than at the total-force level; (iii) for bands with $c/a < 0.5$ no tabulated bound exists and the full one-way strip is used; (iv) for $b/a > 4.0$ the horizontal moment is bounded by the $b/a = 4.0$ tabulated value on physical grounds (the tabulated monotonicity covers only the published range); (v) one residual discrepancy in a single tabulated cell ($M_{x,\text{pos}}[5,3]$) could not be resolved with certainty against the primary source during table verification and is documented as an open item; and (vi) end-to-end validation against a fully worked reference case is limited to the PCA manual's Example 1, so the exact agreement reported in Section 6 is demonstrated for that single geometry and load case; the broader domain is covered indirectly through the automated assertion suite and the double-read coefficient tables rather than through additional independent worked examples.

6.5 Generalisation and future work

Future work includes: the extraction of additional Chapter 3 cases; the extension to circular tanks; the full adoption of ACI 350.3 at the global force level (including P_w and P_r in the base shear and overturning checks); and parametric studies of the conservative envelopes against fine-mesh finite-element solutions.

7 Conclusions

A computational tool for the static and seismic analysis and design of reinforced-concrete rectangular liquid-retaining tanks has been developed and verified. `Tanque.NSR10` integrates the Colombian code NSR-10 (Título C), the seismic standard ACI 350.3 and the tabulated methods of the PCA manual within a single, reproducible and norm-grounded pipeline. The verification strategy – double reading of the coefficient tables, an automated suite of 822 assertions and 144 unit tests, and the exact reproduction of the worked Example 1 of the PCA manual – provides strong evidence of correctness, while every simplification and limitation is explicitly documented. Two findings of general interest are reported: the uniform-load nature of the seismic Case 7 tables, and the conservative extension of the tabulated domain with verified monotonicity. The tool is suitable for practical design and teaching use, and its verification infrastructure, reproducible with the published binary and the accessible suite (the core source is available to reviewers upon request), sets a reference standard for norm-grounded engineering software.

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9 Data and Code Availability

The software `Tanque.NSR10` and the automated verification suite (822 assertions), the 144 unit tests, the confirmed coefficient tables (JSON with page provenance) and the OCR-based extraction tooling are distributed for free download and consultation in a public repository at https://github.com/MauricioVictoriaN/Tanque.NSR10.

The worked Example 1 of the PCA manual is reproduced with the program's own outputs (text and HTML reports).

Supplementary Material

S1. Automated verification suite

The verification tool executes 822 assertions grouped by module, including closed-form recalculation of the conservative envelopes, domain-limit consistency, grid monotonicity, seismic SRSS structure and load factors, and crack-control equations. The complete assertion log is provided in the code repository.

S2. OCR-based table extraction

The double-reading workflow (manual transcription and OCR with pixel-level sign detection) is documented and reproducible with the `tools/OCR_PCA/` tooling, including the language models and the render commands.

S3. Worked example data

The full input and output of the Example 1 validation (governing moments, shears, service checks and reinforcement) are provided as text and HTML reports in the repository.

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