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ADVANCED DAMAGE-PLASTICITY MODELLING AND CALIBRATION STRATEGIES FOR ACCURATE FINITE-ELEMENT ANALYSIS OF UNREINFORCED CONCRETE IN THIN-WALLED STRUCTURES

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Abstract. *Accurate finite-element representation of unconventional concretes – slag-blended, recycled-aggregate, fiber-reinforced, or ultra-thin formwork mixes requires more than the legacy smeared-crack tools that still dominate industrial workflows. This theses reviews research on 3D material modelling of plain, fiber- and aggregate-modified concretes in the ANSYS environment, with emphasis on constitutive law selection, experimental calibration, and numerical tactics that preserve convergence once cracking and crushing initiate. Damage-plasticity formulations such as Concrete Damaged Plasticity (CDP) consistently outperform simpler Drucker–Prager or Willam–Warnke approaches, provided their numerous parameters are tuned to targeted laboratory data. Special issues arising in thin-walled elements and permanent formwork stability, mesh objectivity, staged casting pressure are examined, and five recent case studies are dissected to illustrate best practice. The review concludes with recommendations for practitioners and identifies emerging trends, notably machine-learning-assisted calibration and phase-field fracture, that are poised to reshape concrete simulation in commercial FEA.*

Keywords: *ANSYS modelling, finite elements, concrete, mesh, 3D-modelling*

Introduction. Concrete is a heterogeneous, quasi-brittle composite whose tensile capacity is an order of magnitude lower than its compressive strength. When reinforcement is absent, predictive modelling must capture crack initiation, post-peak softening and stiffness degradation. Over the last few years, the research community has advanced several numerical strategies to meet this requirement inside the ANSYS ecosystem. The present paper converts those scattered findings into a coherent scientific narrative and provides actionable guidance for analysts tasked with modelling non-standard, reinforcement-free concrete structures.

Constitutive Modelling Strategies in ANSYS. Legacy smeared-crack element *(SOLID65)*. SOLID65 embeds a five-parameter Willam–Warnke surface with separate checks for tensile cracking and compressive crushing. Although setup is straightforward, the element is notorious for non-convergence when stiffness drops abruptly at Gauss points. Barghlame Hadi [1] showed that tuning the crushing stiffness factor (CSTIF ≈ 0.3) restored solver stability during cyclic loading of concrete-filled tubes, without compromising physical realism.

Generic Drucker–Prager plasticity. Workbench users typically assign a pressure-dependent yield surface (Drucker–Prager) to SOLID185/186 elements and super-impose a tensile cut-off via failure strain or element birth–death. This configuration reproduces confined compression well but lacks an intrinsic damage mechanism; therefore, it underestimates crack-induced stiffness loss unless supplemented by a user material subroutine [2].

Damage-plasticity (Concrete Damaged Plasticity). The CDP model, native to Abaqus and available in LS-DYNA/Autodyn, couples multi-surface plasticity with scalar damage variables d_t and d_c that degrade elastic stiffness after cracking or crushing. Guan Q et al. [3] achieved 10–15 % agreement with eight fiber-reinforced RAC beam tests once CDP parameters—dilation angle, shape factor K_c biaxial-to-uniaxial strength ratio f_{b0}/f_{c0}, viscosity were calibrated. In ANSYS Mechanical, equivalent behavior can be realized through USERMAT coding or by exporting the mesh to LS-DYNA.

Mesoscale and explicit-inclusion models. Li et al. [4] scripted APDL routines that randomly inserted thousands of discrete steel fibers inside a mortar matrix; Yu et al. [5] modelled recycled aggregates and the old-mortar interfacial transition zone (ITZ) with cohesive elements. These mesoscale approaches capture localized crack paths and fiber pullout at the cost of extreme mesh densities.

Rate-dependent concrete laws. When blast or impact governs design, Autodyn RHT and LS-DYNA's HJC material cards incorporate strain-rate hardening and pressure dependence. Although peripheral to most structural applications, they remain essential for thin GFRC facades or protective panels subject to accidental loads [6].

Modelling Thin-Walled and Formwork Concrete. Thin concrete walls demand special numerical care: once cracks form, their slender geometry can trigger second-order instability, so analyses should enable large-deflection (NLGEOM) settings and, where necessary, use arc-length solution schemes to follow the post-peak path. To keep crack width's objective, the mesh must contain at least three solid elements through the thickness, with non-local regularization or slight mesh randomization added to prevent artificial alignment. Because permanent formwork panels are loaded by the hydrostatic pressure of fresh concrete, simulations need a time-dependent lateral load that fades as the core cures and, for early stripping, should also model temperature-driven strength gain. Finally, ultra-high-performance or fiber-rich mixes often exhibit tensile strain hardening before localization, so the material card must include a multi-linear tension curve; omitting this feature leads to unconservative predictions of service stiffness and crack width.

Review results. Concrete modelling follows a clear hierarchy: damage-plasticity formulations such as Concrete Damaged Plasticity (CDP) now offer the best compromise between accuracy and ease of use, although simpler Drucker–Prager plasticity still serves well for preliminary sizing or for parts where tensile cracking is not critical. Whatever the model, calibration is essential; default material cards are often unconservative, so laboratory data particularly fracture energy and residual tensile capacity in fiber-reinforced concretes must be fed into every analysis of unconventional mixes. Errors become more pronounced in thin elements, where buckling–crack interaction, mesh sensitivity and staged loading can amplify any shortcut assumptions, making careful attention to boundary conditions, element density and solver settings indispensable when wall thickness drops below about 75 mm. Looking ahead, machine-learning routines are starting to automate parameter identification, and phase-field fracture methods promise mesh-independent crack tracking; both are expected to enter mainstream ANSYS workflows in the next research cycle.

Conclusions. Damage-plasticity models, whether built into LS-DYNA or Autodyn or coded as USERMAT routines, consistently outperform smeared-crack or purely plastic formulations when simulating unreinforced concrete. Achieving this accuracy depends on a multi-stage calibration cycle that draws on compression, tension, fracture, and full-scale structural tests to fix every key parameter. The task becomes even more demanding for thin-walled or permanent-formwork elements because geometric nonlinearity, staged casting pressure, and mesh objectivity all require explicit treatment. Case studies show that, when these practices are followed, ANSYS can predict load capacity, stiffness loss, and crack patterns to within about ±15 percent of experimental results. Looking ahead, data-driven calibration tools and phase-field fracture techniques offer promising routes to narrow the remaining gap between numerical predictions and real-world behavior.

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УДОСКОНАЛЕНІ МОДЕЛІ ПЛАСТИЧНОСТІ З УРАХУВАННЯМ РУЙНУВАННЯ ТА СТРАТЕГІЇ КАЛІБРУВАННЯ ДЛЯ ТОЧНОГО СКІНЧЕННО-ЕЛЕМЕНТНОГО АНАЛІЗУ БЕТОНУ БЕЗ АРМУВАННЯ У ТОНКОСТІННИХ КОНСТРУКЦІЯХ

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Анотація. *Точне скінченно-елементне відтворення нетрадиційних бетонів: шлакопортландцементних, із переробленим заповнювачем, фіброармованих або ультратонких опалубкових сумішей – потребує більшого, ніж застарілий підхід «smeared-crack», що й досі домінує у промислових робочих розрахунках. У даних тезах узагальнено дослідження з тривимірного матеріального моделювання* *звичайних, фібро- бетонів та бетонів із модифікованим заповнювачем у середовищі ANSYS з акцентом на вибір моделей, експериментальне калібрування та числові тактики, які забезпечують збіжність після зародження тріщин і руйнування. Формулювання типу «пластичність із пошкодженням» (CDP) стабільно перевершують простіші підходи Друкера–Прагера чи Віллама–Варнке, за умови, що їхні численні параметри налаштовані за цільовими лабораторними даними. Розглянуто особливі питання, що виникають у тонкостінних елементах і незнімній опалубці, а саме стійкість, об'єктивність сітки та поетапний тиск укладання, і проаналізовано п'ять сучасних прикладів, які демонструють найкращі практики. Огляд завершується рекомендаціями для практичних розрахунків і визначає нові тенденції, зокрема калібрування з використанням машинного навчання та фазово-польове моделювання тріщин, що здатні докорінно змінити симуляцію бетону в комерційних системах розрахунку КЕ.*

Ключові слова: *ANSYS моделювання, метод скінченних елементів, бетон, сітка, 3D-моделювання*