Hydrostatic Compression and FEA Engineering Guide

Practical guide to source-controlled bulk modulus calculations, material model selection, near-incompressibility risks, FEA evidence and manufacturing RFQ qualification.

What this guide does

• Explains the engineering conditions for interpreting bulk modulus, compressibility and elastic constants.

• Separates a **derived** K from an actually **measured** pressure-volume response.

• Provides calculation and audit steps that are tied to the two accompanying Excel workbooks.

• Identifies conditions that require additional constitutive data or solver-specific verification.

Use sequence

Step	Deliverable	Hard requirement
01	Identify material	Exact grade, product form, condition and batch/lot when relevant
02	Qualify property data	Test method, temperature, strain/rate, uncertainty and source ID
03	Calculate or import K	Clearly identify derived versus measured input
04	Run sensitivity and FEA review	Constitutive assumptions, near-incompressibility and formulation
05	Compare independent evidence	Pre-set acceptance limit, actual measurement and approval

No example parameter in this guide represents a guaranteed commercial material property.

1 | Bulk Modulus and Physical Meaning

Bulk modulus K is the hydrostatic pressure increment divided by the negative change in relative volume in a local linear approximation. Compression-positive pressure is used in the equations below.

Local definition: K = -V (dp/dV). **Small interval / secant approximation:** K_secant ~= -Delta p / (Delta V / V0).

For a small compressive increment, Delta V / V0 ~= -Delta p/K. As pressure rises, Delta V is negative. K has pressure units (Pa, MPa, GPa); compressibility beta = 1/K has reciprocal pressure units.

Do not confuse different elastic responses

Property	Loading	What it measures
K, bulk modulus	Hydrostatic pressure	Volumetric stiffness
E, Young modulus	Axial normal stress	Axial elastic stiffness
G, shear modulus	Shear stress	Shear distortion stiffness
Ec, compression modulus	Uniaxial compression	Axial compressive behavior under test conditions

Uniaxial compression allows lateral deformation and does not directly establish bulk modulus. ASTM D695-26 and ISO 604:2002 are compression property methods, not universal hydrostatic bulk modulus measurement standards.

2 | Elastic Constants and Calculations

Only for homogeneous, isotropic, small-strain, linear-elastic solids:

Relationship	Expression / requirements
Bulk from E, nu	K = E / [3(1 - 2 nu)]
Shear from E, nu	G = E / [2(1 + nu)]
Lamé first parameter	lambda = E nu / [(1 + nu)(1 - 2 nu)]
Young from K, G	E = 9 K G / (3 K + G)
Poisson from K, G	nu = (3 K - 2 G) / [2(3 K + G)]
Poisson from E, G	nu = E/(2G) - 1
Poisson from E, K	nu = (3K - E)/(6K)
Compressibility	beta = 1/K

A stable 3D isotropic elastic material requires E > 0, K > 0, G > 0 and -1 < nu < 0.5. K diverges mathematically as nu approaches 0.5 at fixed E. Exact nu = 0.5 cannot be entered in the ordinary conversion equation.

The formulas are constitutive conversions, not test-method equations. The workbook intentionally outputs a "DERIVED" label and refuses numerically inadmissible inputs.

3 | Hydrostatic Pressure-Volume Checks

Step A: define units and sign convention

Convert the pressure increment to MPa, record initial V0 in mm3, and define compressive pressure as positive. Do not combine a gauge pressure difference with absolute-volume values from incompatible baseline states.

Step B: use a documented K

For the small-strain model, Delta V = -(Delta p/K) V0 and V1 = V0 + Delta V. For a measured pressure-volume interval, K_secant ~= -Delta p / [(V1 - V0)/V0].

Illustrative numerical check (not measured data)

Set E = 3850 MPa, nu = 0.380, Delta p = 20 MPa and V0 = 1000 mm3. K = 3850/[3(1 - 0.760)] = 5347.222 MPa. Delta V/V0 = -20/5347.222 = -0.00374026, or -0.374026%; Delta V = -3.74026 mm3 and V1 = 996.25974 mm3.

What an engineering review still needs

• A documented linear elastic interval and operating-temperature data.

• An explanation of material/void/compliance effects in the test chamber and volume sensor.

• Calibration and repeatability records and uncertainty appropriate to the magnitude of strain.

• A separate part-level structural verification for geometry, strength, contact and instability.

4 | Material Data Qualification

Never copy a K, E or nu value solely because the base material name matches. The usable dataset is a property of the specified material state and test conditions, not a universal number for "aluminum", "PEEK" or "nylon".

Required field	Why it matters
Commercial grade + manufacturer	Grades, fillers and processing routes can differ.
Batch, heat or lot	Supports traceability when the project requires lot-specific qualification.
Condition / temper / moisture	Heat treatment, conditioning and water uptake can change measured response.
Temperature, time, loading rate	Relevant especially to polymers and time-dependent materials.
Direction, geometry and build process	Essential for anisotropic/printed/composite materials.
Source and revision	Distinguishes supplier typical data from actual measurement.
Uncertainty and sample count	A rounded point estimate does not describe confidence.

The source register workbook provides a controlled record of all fields. Data without adequate evidence should be marked NEEDS REVIEW rather than populated with a guessed commercial value.

5 | Poisson Sensitivity and Near-Incompressibility

Sensitivity is inherent in K = E/[3(1 - 2 nu)]. Small uncertainty in nu near 0.5 produces a large change in derived K even while E is held fixed.

nu	K from E = 3850 MPa	K/G ratio	Interpretation
0.38	5347.2 MPa	3.833	Baseline calculation, illustrative
0.49	64166.7 MPa	49.667	Strong near-incompressible sensitivity
0.495	128333.3 MPa	99.667	Solver formulation review critical
0.499	641666.7 MPa	499.667	Extreme sensitivity to rounded nu

Solver-specific statement: Abaqus 2026 documentation recommends hybrid solid continuum elements in Abaqus/Standard for isotropic linear elastic material with nu > 0.495 (K/G > 100). This is not a universal numerical criterion for other software, element types or constitutive models.

Abaqus also discusses near-incompressibility concerns for nu > 0.49 in its broader linear-elastic material guidance. For other solvers, consult the relevant official element and material formulation documentation.

6 | Material Model Selection for FEA

Material response	Typical model direction	Do not assume
Small strain, isotropic, linear	E/nu or K/G pair	Transfer between unlike temperature/lot states
Orthotropic / laminate	Directional elastic tensor	A single K computed from one E and nu
Hyperelastic elastomer	Calibrated nonlinear model	Constant modulus across large strain
Viscoelastic polymer	Rate/time/temperature behavior	One E/nu pair for all frequencies
Foam / porous	Compressible nonlinear constitutive response	Dense-solid hydrostatic relation applies
Elastoplastic metal	Elastic + plastic hardening data	Bulk modulus replaces yield verification

Additional model controls

• Check mesh convergence for the particular quantity used in the acceptance decision.

• Use realistic supports, pressure distribution and contact; local part deformation cannot be inferred from K alone.

• Review actual applied state, parameter source and solver warnings, not just successful solver convergence.

7 | Correlation, Acceptance and Release

A verification result requires an independent measurable response and an acceptance criterion defined for that project. Typical responses are volumetric strain, local contraction, displacement or another functional dimension; the solver and test must use the same definitions, units and sign convention.

Verification input	Release requirement
FEA quantity / value	Documented model ID, mesh, material, pressure and solver revision
Physical observation	Original calibrated test record, environmental condition, uncertainty
Acceptance limit	Explicit numerical basis approved before comparing results
Difference calculation	Absolute or normalized difference using compatible units
Decision	PASS only with complete evidence and within agreed limit
Approval	Authorized reviewer and controlled approval record

A spreadsheet mathematically comparing two numbers does not establish material validation. Records labeled ILLUSTRATIVE, missing a tolerance or lacking evidence remain open.

8 | Manufacturing, Procurement and RFQ Use

For purchased parts with pressure-sensitive dimensional function, include material identity, test state, acceptance basis and traceability requirements in the RFQ package. When a bulk modulus calculation informed design, link the drawing/FEA revision to the material-source record.

Recommended RFQ and quality data

• Exact commercial grade, stock form, condition, lot/heat traceability, direction and manufacturing route.

• Material certificate, relevant property test report and applicable engineering test method.

• Critical dimensions and pressure/function test where justified by design risk.

• Source-controlled FEA model revision and disposition of open material-data uncertainty.

• Defined project acceptance limits; never claim universal pressure performance from a material name alone.

A supplier quotation is not proof of a constitutive property or functional performance. The purchasing decision should identify the required certificates and independent verification.

9 | Verified Standards and Interpretation

The following designation/version and scope titles were checked against the publishing organizations, as of 21 November 2026. They provide property or compression-testing boundaries, not a generic direct hydrostatic bulk modulus method.

Standard	Verified scope and appropriate use
ASTM E111-17(2025)e1	Young, tangent and chord moduli. Does not directly measure K.
ASTM E132-17(2025)e1	Poisson ratio at room temperature. Match E source conditions.
ASTM D638-22	Tensile properties of plastics; not a hydrostatic K method.
ASTM D695-26	Compressive properties of rigid plastics, uniaxial.
ISO 604:2002	Plastics determination of compressive properties, uniaxial.
Abaqus 2026 docs	Solver-specific near-incompressibility/element guidance; not a test standard.

In this document, the above standards are referenced by identity and purpose only. Official standard full text, sample geometry, apparatus, rate selection, conditioning and reporting requirements must be followed separately where applicable.

No external-domain URLs are included in this guide. Only EPOC CRAFTER website and RFQ links appear as hyperlinks.

10 | Practical Closeout Checklist

• Confirm material identity, physical condition and batch/lot when relevant.

• Record E and nu provenance from compatible material and loading states.

• Select appropriate constitutive model: linear isotropic only when justified.

• Convert to standard MPa units and independently cross-check K and G.

• Assess nu sensitivity, K/G and solver-dependent formulation requirements.

• Link numerical outputs to original measured pressure-volume evidence.

• Compare the same response quantity under equivalent geometry and load conditions.

• Establish explicit tolerance, measurement uncertainty, review and signoff.

• Include material and verification requirements in procurement / RFQ records.

Associated controlled worksheets: Bulk Modulus and Elastic Constants Calculator; Poisson Ratio Sensitivity and FEA Validation. Associated review document: Bulk Modulus Material Data Verification Checklist.

Scope note: This engineering resource is not an accredited laboratory report, material certificate or substitute for project-specific analysis and approval.