FEA ACADEMY

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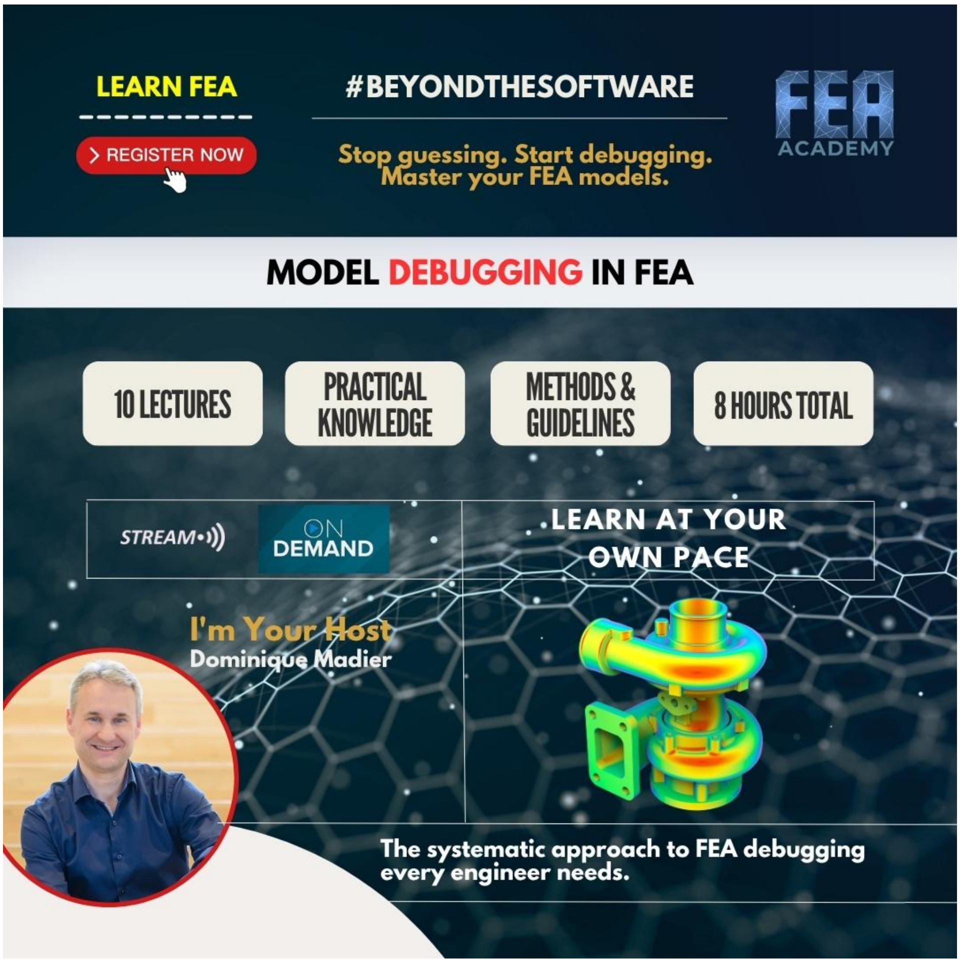
Model Debugging in FEA

Course Overview & Curriculum Guide



Instructors

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Course Overview

Model Debugging in FEA is an intensive, practice-oriented course that teaches finite element analysis practitioners how to systematically identify, diagnose, and resolve errors in FEA simulations. Rather than treating debugging as a reactive troubleshooting exercise, this course establishes it as a core professional discipline, a structured engineering process that builds confidence, repeatability, and credibility into every analysis.

All concepts are illustrated with practical examples drawn directly from the instructors' day-to-day consulting work with industry clients. The course progresses from foundational verification methods through convergence diagnosis to advanced debugging techniques, culminating in hands-on challenges where participants debug real models containing embedded errors.

The course is structured around three sessions, each containing multiple lectures, for a total of ten lectures combining theory, worked examples, decision workflows, and guided exercises.

Target Audience

This course is designed for engineers and analysts who use finite element analysis in their professional work and want to move from ad hoc troubleshooting to systematic, efficient model debugging. Specifically, it is suited for:

- **Practicing FEA engineers** working in sectors such as transportation (aerospace, automotive, marine, rail), energy, structural and civil engineering, biomedical and orthopedics, heavy machinery, consumer products, or robotics, who regularly build and run FEA models and need to ensure result reliability.
- **Design engineers** who use simulation to justify sizing, safety margins, and certification decisions and need a rigorous verification and validation workflow.
- **Intermediate to advanced analysts** who are comfortable building models and running solvers but want to strengthen their diagnostic skills when convergence fails or results look suspicious.
- **Team leads and simulation managers** who want to establish quality standards, checklists, and a debugging culture within their FEA teams.
- **Engineers transitioning to nonlinear analysis** who encounter convergence issues for the first time and need a structured approach rather than trial-and-error.

Prerequisites: Participants should have working knowledge of FEA concepts (meshing, boundary conditions, element types, solver execution) and hands-on experience running at least linear static analyses in a commercial FEA package.

Deliverables & Learning Materials

Participants receive a comprehensive set of materials designed for both in-course learning and long-term reference:

Presentation Slides

- Fully developed lecture slide decks covering all theoretical content, worked examples, diagnostic tables, decision trees, and reference cards.

Checklists & Workflows

- **18-item Accuracy Check list** — a systematic pre-processing verification list covering dimensions, units, materials, mesh quality, connectivity, shell normals, coordinate systems, mass, and more.
- **3 Mathematical Validity Checks** — detailed setup and inspection procedures for the free-free modal check, unit gravity/enforced displacement check, and free thermal strain check.
- **Pre-analysis checklist** — a comprehensive gate to complete before submitting any nonlinear run (model integrity, constraints and loads, mesh and formulation, nonlinear setup).
- **Post-analysis checklist** — a structured post-processing verification covering solution quality, displacement results, stress results, and equilibrium.
- **6-step Universal Debugging Workflow** — the course's central framework applicable to any FEA problem.

Diagnostic Reference Material

- **Troubleshooting decision trees** — two flowcharts for convergence failure and suspicious results, guiding the analyst from symptom to root cause.
- **Symptom-to-root-cause tables** — quick-reference tables mapping observed symptoms to likely causes and first-check actions.
- **Contact diagnostic toolbox** — six specific checks (initial status map, status history, pressure distribution, penetration depth, force vectors, energy ratio) with pass/fail criteria.
- **Energy debugging protocol** — four energy-based checks.
- **The 10 Golden Rules of FEA Debugging** — a concise one-page summary of the professional principles taught throughout the course.

Hands-on Exercises

- Guided debugging exercise (Session 1) applying the verification toolkit to a model with embedded errors.
- Real-world case studies (Session 2) demonstrating full debugging workflows on complete models.
- Apply advanced debugging concepts on real FEA models (Session 3)

Detailed Curriculum

SESSION 1 — Understanding Common Modeling Errors & Verification Methods

This session establishes the foundational debugging mindset and equips participants with verification tools that catch the majority of model errors before the solver is ever launched.

Lecture 1.1 — Introduction to Model Debugging

Building Confidence in Your FEA Results

This opening lecture makes the professional case for treating debugging as preventive engineering rather than damage control. It establishes the critical distinction between Verification (are we solving the equations correctly?) and Validation (are we solving the correct equations?), a distinction that underpins the entire course.

Topics Covered

- **Why debugging matters**
- **The professional analyst mindset**
- **Verification vs. Validation**
- **Common model setup challenges**
- **The 6-step systematic debugging workflow**

Learning Outcomes

1. Distinguish between Verification and Validation and explain why both are required.
2. List the main sources of FEA model setup errors before the solver is launched.
3. Apply the 6-step systematic debugging workflow to any FEA model.
4. Explain why debugging is preventive engineering, not damage control.

Lecture 1.2 — Common Modeling Errors and How to Detect Them

The Fastest Discriminating Test Wins

This lecture provides a comprehensive catalogue of common FEA modeling errors organized by family, each presented with symptoms, fast detection checks, and fix directions. The guiding principle is to run the cheapest test that eliminates the most hypotheses.

Topics Covered

- **Debugging methodology**
- **Geometry & meshing issues**
- **Boundary conditions issues**
- **Contact & nonlinearities issues**
- **Solution and IT issues**

- **Debugging triage order**

Learning Outcomes

1. Identify the main families of FEA modeling errors and recognize their typical symptoms.
2. Apply fast, high-value diagnostic checks to isolate likely root causes in minutes.
3. Follow a structured debugging triage order to avoid random trial-and-error.

Lecture 1.3 — The Model Verification Toolkit: Checking the Fundamentals

A Structured Pre-Solve Quality Gate

The most comprehensive lecture in Session 1, this covers the complete model verification toolkit: eighteen accuracy checks performed in the pre-processor and three mathematical validity checks performed as simple analyses. This is the primary quality gate when no physical test data is available.

Part A — Accuracy Checks (18 items)

Part B — Mathematical Validity Checks (3 analyses)

Supporting Concepts

The lecture also covers five supporting concepts essential for interpreting mathematical check results: the singularity and grid point singularity table, the epsilon vector (residual error measure), the weight check, the applied loads check, and the reacted loads check (equilibrium verification).

Learning Outcomes

1. Distinguish clearly between accuracy checks and mathematical checks.
2. Perform all 18 accuracy checks systematically.
3. Apply the three mathematical validity checks: free-free modal, unit gravity, and free thermal strain.
4. Use a structured verification checklist to remove modeling errors early.

Lecture 1.4 — Hands-on Debugging Exercise

Putting the Toolkit to Work on a Live Model

This guided exercise applies the verification toolkit from Lectures 1.1–1.3 to a real FEA model containing embedded errors. Participants work through the checks, identify issues, and apply corrective actions under instructor guidance. This exercise bridges the gap between theory and practice, ensuring participants can apply the workflow on their own models.

SESSION 2 — Debugging Non-Linear Convergence and Result Validation

This session addresses the two most common classes of FEA problems: convergence failures and suspicious results. It teaches participants to read solver diagnostics, understand what the solver is doing, and systematically trace problems to their root cause.

Lecture 2.1 — Understanding Non-Linear Convergence Issues

Stop Guessing. Start Diagnosing.

This lecture demystifies convergence by explaining what the implicit solver is actually doing, why it fails, and how to identify the root cause systematically.

Topics Covered

- **Convergence in implicit solvers**
- **The Newton-Raphson process**
- **Four major convergence drivers**
- **Mesh quality impact on convergence**
- **Element formulation reference**
- **Load stepping and tolerances**
- **Convergence debugging workflow**
- **Symptom-to-root-cause quick reference**

Learning Outcomes

1. Explain how an implicit solver iterates and what causes it to fail.
2. Identify the four main convergence drivers: mesh, settings, material, and contact.
3. Apply a structured diagnostic approach to isolate the root cause of convergence failure.
4. Adjust solver settings intelligently, not randomly.

Lecture 2.2 — Troubleshooting Analysis Output

From Suspicious Results to Confident Conclusions

This lecture addresses the equally critical problem of results that converge but are wrong or suspicious. It provides a systematic toolkit for post-processing verification.

Topics Covered

- **Displacement consistency checks**
- **Stress consistency checks**
- **Numerical artifacts — stress singularities**
- **Unexpected deformations and rigid body motion**
- **Reaction force evaluation**

- **Pre-analysis and post-analysis checklists**
- **Troubleshooting decision trees**
- **Common result pathologies**

Learning Outcomes

1. Verify displacement and stress results for physical consistency.
2. Correctly interpret stress singularities without misreading them as structural failures.
3. Diagnose unexpected deformations using visual inspection and reaction force analysis.
4. Evaluate reaction forces to confirm global equilibrium.
5. Apply structured pre- and post-processing checklists.

Lecture 2.3 — Case Studies: Real-world Debugging Examples

Walkthrough of Debugging Steps Applied to Real FEA Models

This lecture applies the full debugging workflow from Sessions 1 and 2 to complete, real-world FEA models. Participants observe the step-by-step diagnosis of embedded errors — from initial symptom recognition through solver log analysis, simplification strategy, root cause identification, and corrective action — demonstrating how the theory translates to professional practice.

SESSION 3 — Advanced Debugging & Best Practices

The final session covers advanced diagnostic techniques for the most challenging FEA scenarios and consolidates all course material into professional best practices and an actionable implementation plan.

Lecture 3.1 — Advanced Debugging Techniques

Mastering the Toughest Debugging Scenarios

This lecture equips participants with the advanced diagnostic tools needed for the most difficult FEA debugging scenarios, including snap-through instabilities, contact failures in complex assemblies, and large-deformation analyses.

Topics Covered

- **Solver logs and error messages**
- **Force vs. displacement control**
- **Element energy checks**
- **Debugging contact models**
- **Simplified model strategy**
- **Large deformations and instabilities**

Learning Outcomes

1. Extract actionable diagnostic information from solver log files.
2. Decide when to switch from force control to displacement or arc-length control.
3. Use strain energy and hourglass energy checks to identify mesh problems.
4. Systematically diagnose contact models using six specific outputs.
5. Build and run minimal debugging models to isolate root causes.
6. Handle snap-through instabilities and large deformations using arc-length methods.

Lecture 3.2 — Walk Through a Full Analysis

Apply advanced debugging concepts on real FEA models

Presentation of a structured workflow covering pre-analysis verification, solver log analysis, model simplification, root cause identification, contact problems, and corrective action.

Lecture 3.3 — Course Wrap-Up and Key Takeaways

Recap, Workflow, Best Practices, and Next Steps

The final lecture consolidates all course material into a unified framework and prepares participants for immediate application in their professional work.

Topics Covered

- **Course recap by session**
- **The Universal Debugging Workflow**
- **Debugging decision matrix**
- **Best practices consolidation**
- **The Professional FEA Analyst Mindset**
- **The 10 Golden Rules of FEA Debugging**
- **Next steps and implementation plan**

Learning Outcomes

1. Apply the Universal Debugging Workflow to any FEA analysis.
2. Use the decision matrix to rapidly identify the correct diagnostic path.
3. Implement the complete set of best practices in their daily FEA work.
4. Begin building a personal debugging reference library.

Course Structure Summary

Lecture	Title	Focus	Format
1.1	Introduction to Model Debugging	V&V, debugging mindset, 6-step workflow	Theory
1.2	Common Modeling Errors	Error families, triage order, diagnostic tables	Theory + examples
1.3	Model Verification Toolkit	18 accuracy checks, 3 mathematical checks	Theory + demonstrations
1.4	Hands-on Debugging Exercise	Apply verification toolkit to a real model	Guided exercise
2.1	Understanding Convergence	Newton-Raphson, 4 convergence drivers, formulation	Theory + examples
2.2	Troubleshooting & Results	Post-processing checks, singularities, checklists	Theory + workflows
2.3	Case Studies	Full debugging on real models	Instructor-led walkthrough
3.1	Advanced Debugging	Solver logs, energy, contact toolbox, arc-length	Theory + reference
3.2	Advanced Excercices	Advanced debugging	Hands-on exercise
3.3	Course Wrap-Up	Universal workflow, best practices, golden rules	Consolidation + planning

About the Instructors

Dominique Madier — Founder of FEA Academy (fea-academy.com), a specialist platform dedicated to FEA training, mentoring and consulting. With extensive industry experience, Dominique brings a practitioner-first approach to teaching simulation engineering, ensuring every concept is grounded in real-world application.

Dr. Steffan Evans — Director of Evotech CAE (evotechcae.com), providing FEA and CAE consultancy services across multiple industries. Dr. Evans leads the hands-on exercises and case studies, bringing direct experience from debugging complex client models in his day-to-day consulting work.

For more information and registration: www.fea-academy.com