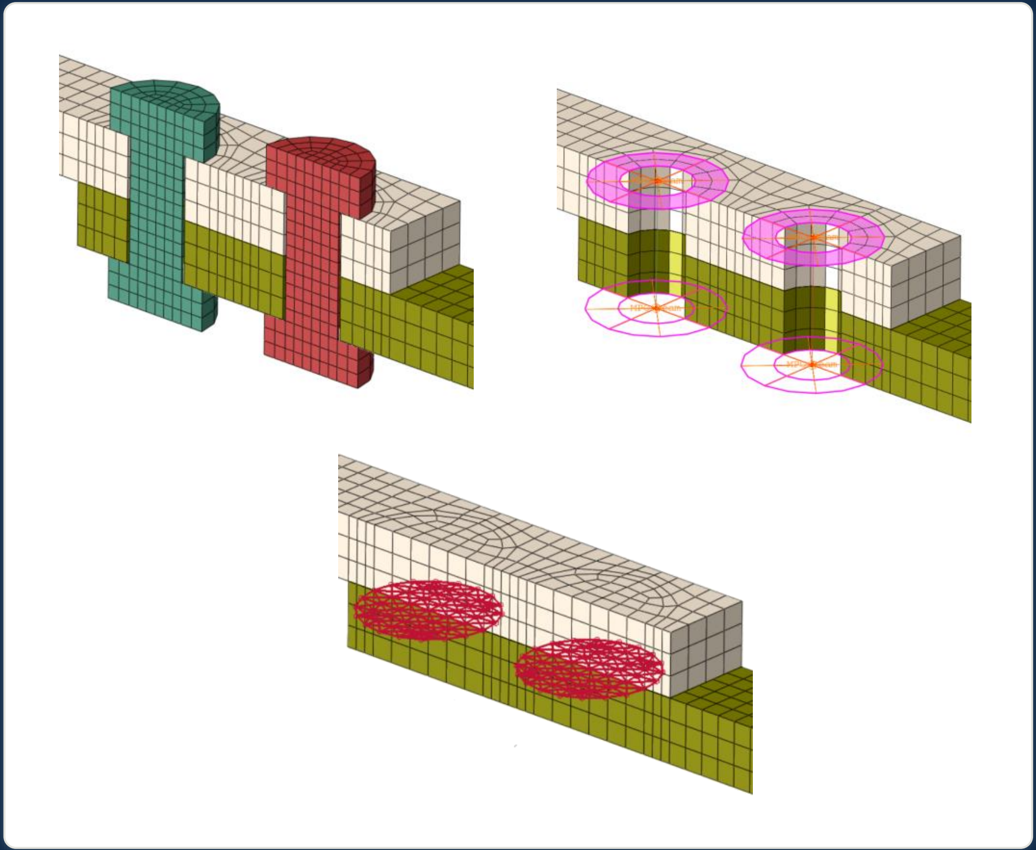
STRUCTURAL ANALYSIS LEARNING SERIES

Three Ways to Model a Bolted Joint

Solid bolt, beam with couplings, and a tie constraint — the same joint built three ways, then compared through preload, modal and static analysis.

Abaqus · Benchmark study



- **M1** Solid Bolt
- **M2** MPC – Beam – MPC
- **M3** Tie Constraint

Dağhan Günhan

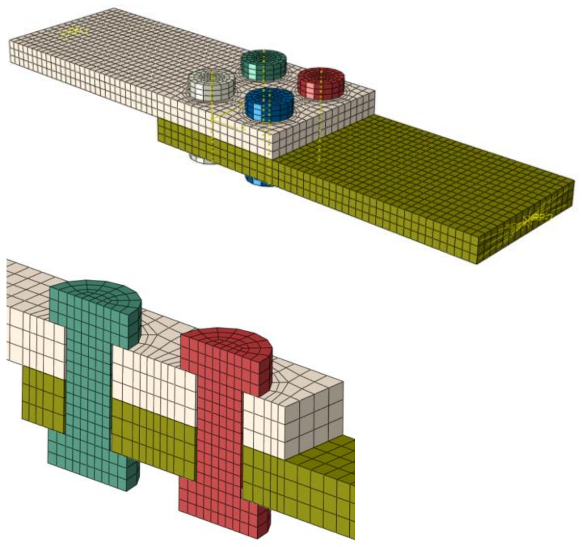
STRUCTURAL DESIGN | ANALYSIS | TEST

daghangunhan.com

The same joint, built three ways

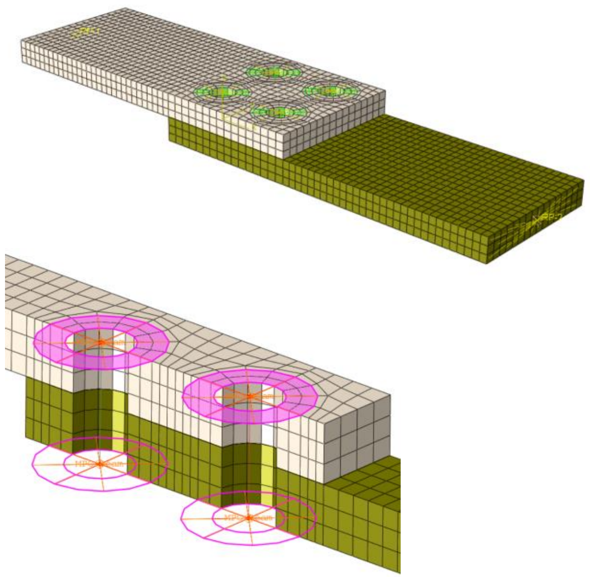
Identical mesh and material in all three. Only the bolt representation changes.

M1 Solid Bolt



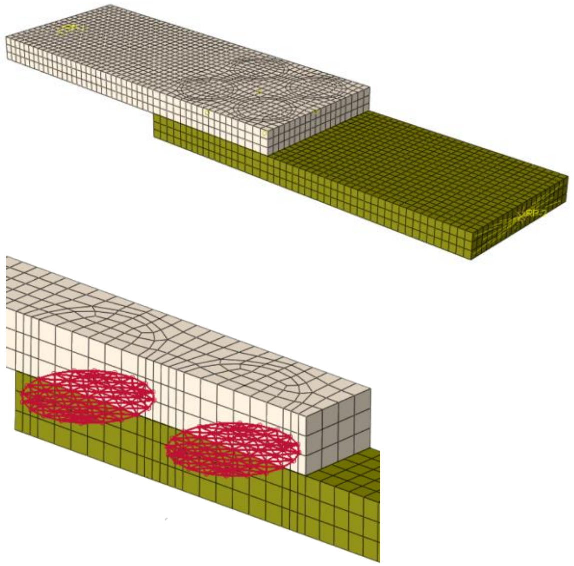
- Bolt meshed as a solid body.
- Contact defined between all mating surfaces.
- Preload applied directly to the shank.

M2 MPC – Beam – MPC



- Bolt replaced by a beam element.
- Connected to the hole surfaces through kinematic couplings.
- Preload applied on the beam.

M3 Tie Constraint

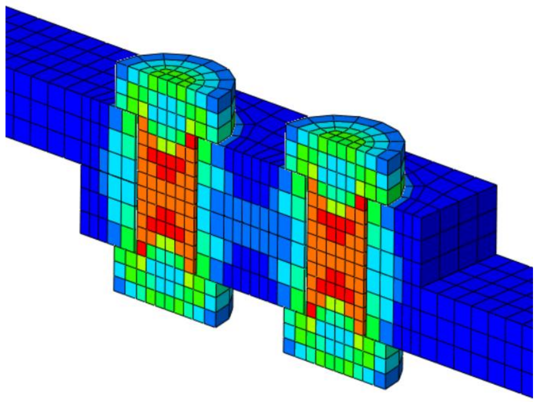


- No bolt body, no contact.
- The two plates are tied over the washer footprint.
- No preload.

Preload: only two of the three can carry it

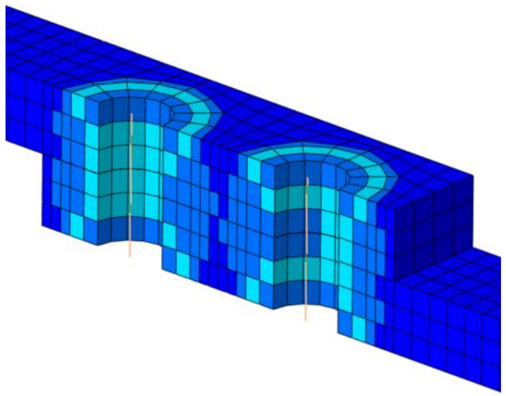
Bolt preload step. Von Mises stress on the section through the bolt row.

M1 Solid Bolt



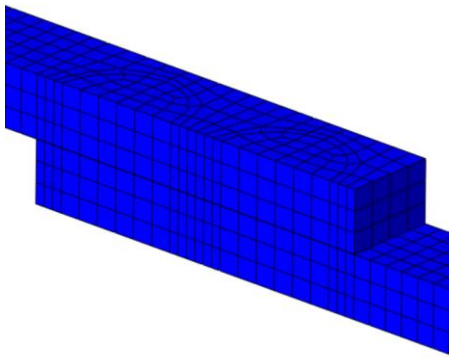
Preload develops in the shank and spreads into the plates as a clear compression cone.

M2 MPC – Beam – MPC

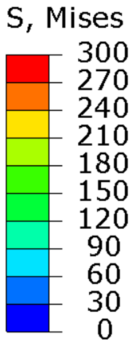


The beam carries the preload; the couplings transfer it to the hole surfaces.

M3 Tie Constraint



Nothing happens. A tie constraint bonds the parts — there is no bolt to pretension.



Takeaway

If clamping force is part of your question — joint separation, slip, bolt fatigue — a tie constraint cannot answer it. The choice is already made at this step.

Modal analysis: the differences stay small

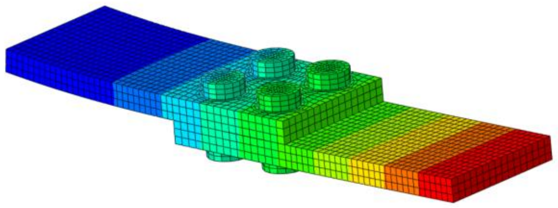
First two bending modes of the assembled joint.

M1 Solid Bolt

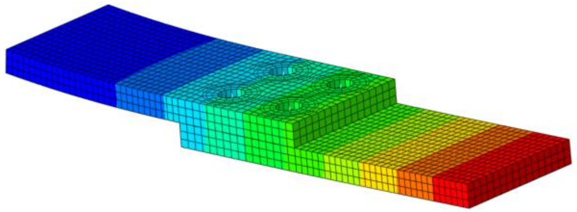
M2 MPC – Beam – MPC

M3 Tie Constraint

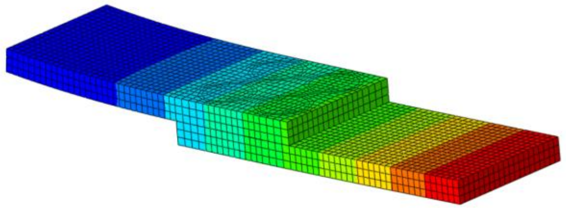
MODE 1
BENDING



129 Hz

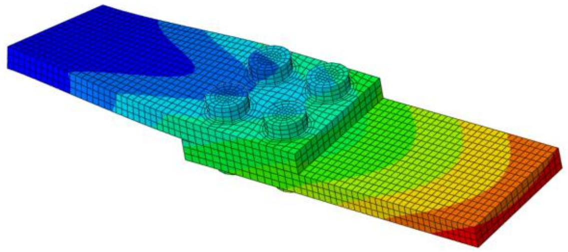


133 Hz

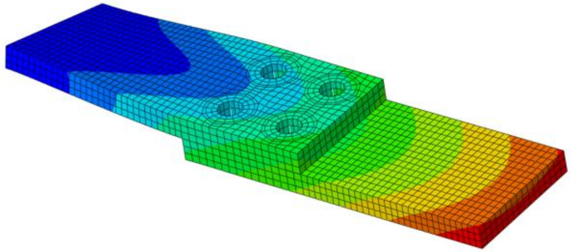


131 Hz

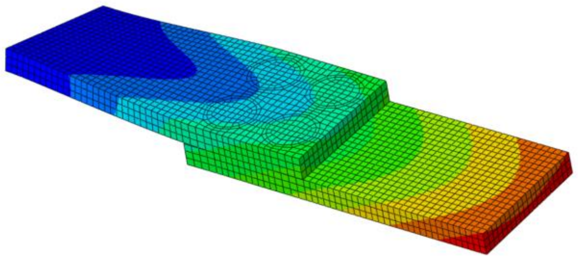
MODE 2
TORSION



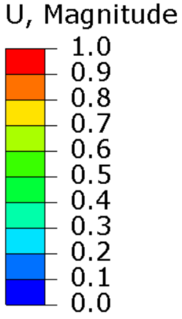
710 Hz



739 Hz



727 Hz

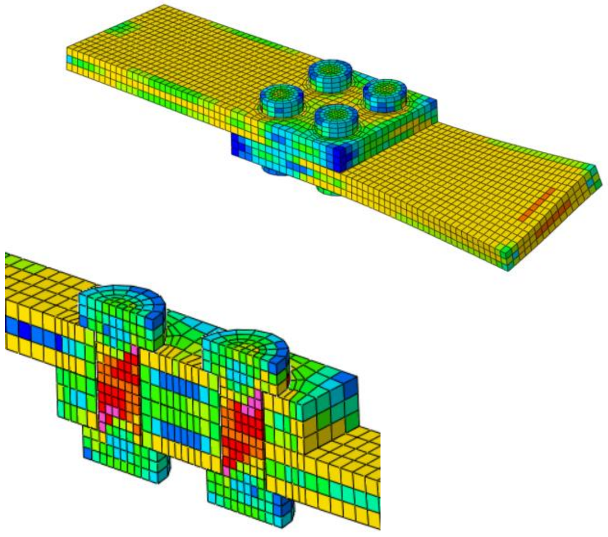


Mode 1 spread: 129 – 133 Hz (~3%). Mode 2 spread: 710 – 739 Hz (~4%). For global dynamics, all three answer the same question.

Static step: where the models disagree

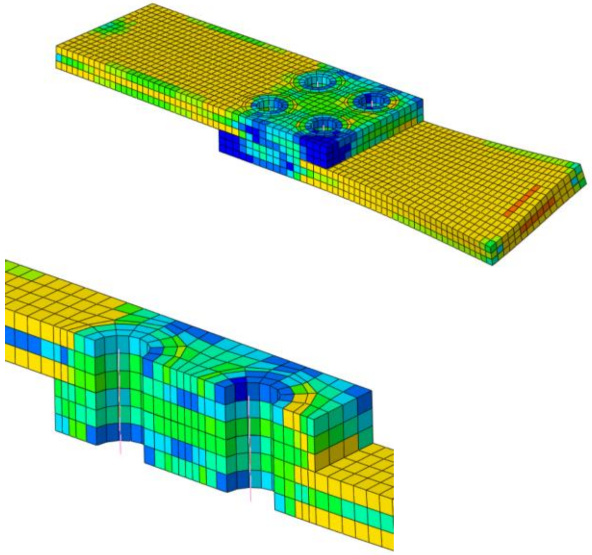
Von Mises stress under an applied moment. Same scale, same deformation factor.

M1 **Solid Bolt**



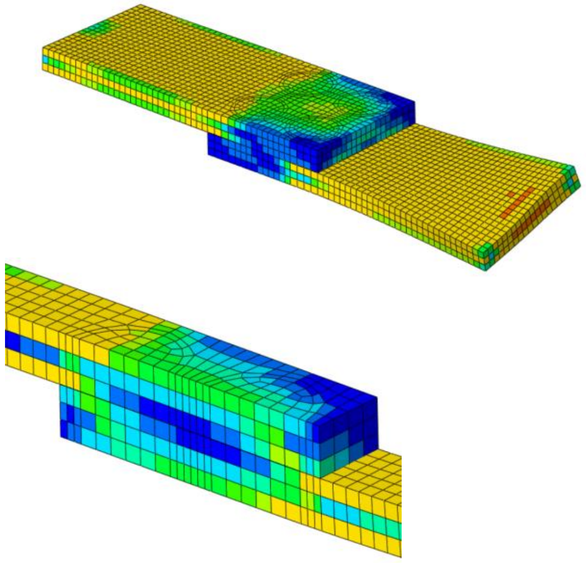
Load path runs through the shanks. Local peaks under the bolt heads and around the holes.

M2 **MPC – Beam – MPC**

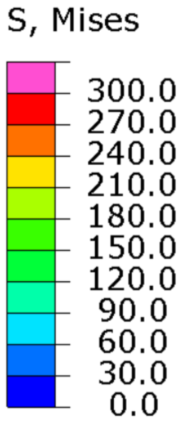


Load is transfered through the couplings. The hole edge is stiffened, so the local field is smoothed.

M3 **Tie Constraint**



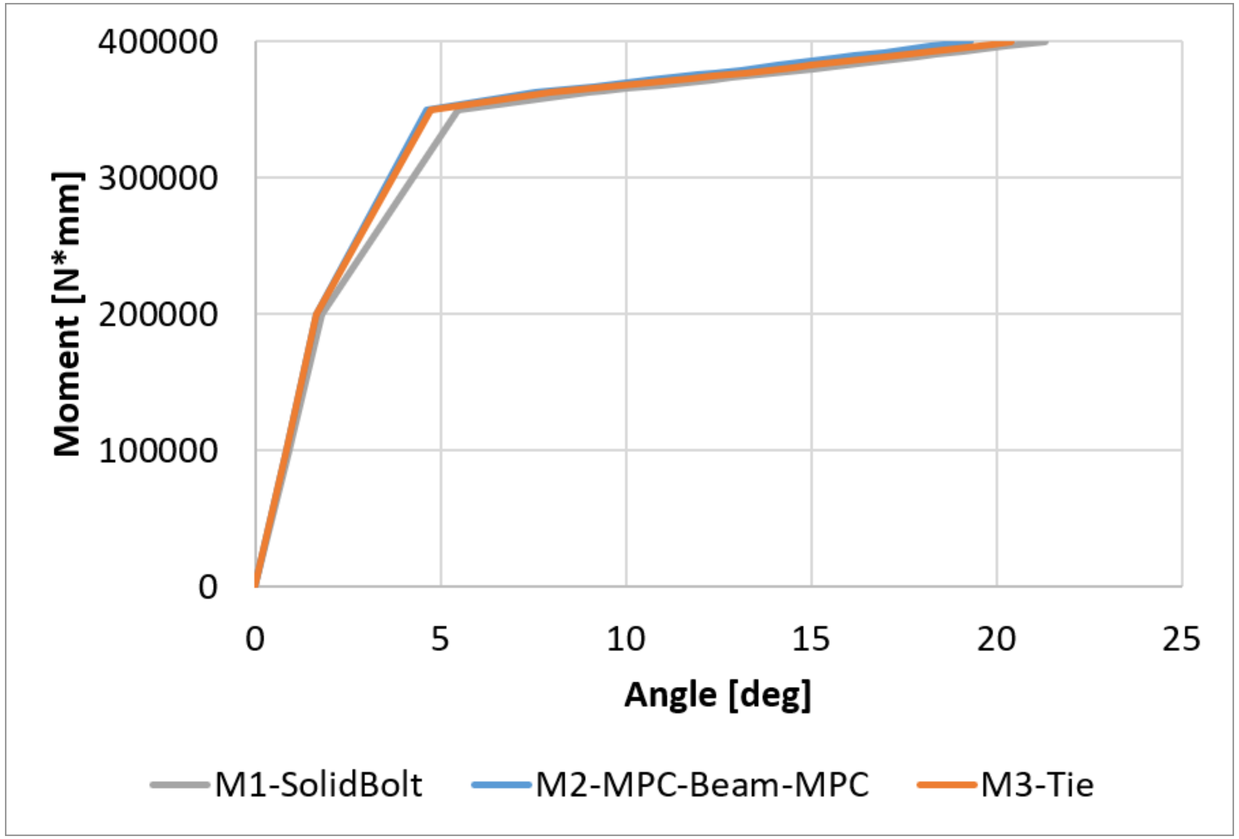
The bonded patch carries everything. No hole, no bolt head, no local peak.



Global stiffness is nearly identical. Local stress at the joint is not.
If you are reading peak stress near the bolt, the model choice is your result.

Moment – rotation: three curves, one answer

Applied moment against joint rotation, from the static step.



What the curves say

1 Same initial stiffness

All three follow one line up to first yield. Global stiffness barely depends on how the bolt is built.

2 Same plateau

The curves flatten together. Capacity is governed by the plates, not the bolt representation.

3 Small divergence only

The solid bolt is marginally softer. Contact and shank compliance are real, but second order here.

A matching global curve is not proof that the local model is right.

Choosing between them

There is no best method. There is a method that fits the question you are asking.

Method	Preload	Local stress	Cost	Use it when
M1 Solid Bolt	Yes — full clamping	Most realistic	High	Bolt fatigue, joint separation, slip, contact pressure, detailed local stress
M2 MPC – Beam – MPC	Yes — on the beam	Smoothed near the hole	Moderate	Bolt forces in large assemblies, many joints, preload needed without solid meshing
M3 Tie Constraint	**No**	Not representative	Low	Global stiffness and modal studies where the joint is assumed to stay closed

The engineering question comes first

Before choosing a bolt modelling method, decide what you need to read from the result. Global stiffness, a bolt force, or a stress next to the hole are three different questions — and they do not need the same model.

What this benchmark shows

01

Global behaviour is forgiving

Modal frequencies within ~4% and near-identical moment–rotation curves. For overall stiffness and dynamics, the simplest model is often enough.

02

Local behaviour is not

Stress next to the hole, under the head, and in the contact zone changes with the method. A matching global curve proves nothing locally.

03

Preload decides early

A tie constraint cannot carry clamping force. If separation, slip or bolt fatigue matter, that method is out before you start.

A good model does not reproduce the geometry.
It reproduces the behaviour you need to read.

Dağhan Günhan
STRUCTURAL DESIGN | ANALYSIS | TEST
daghangunhan.com