CDPM2 UMAT Analysis Examples

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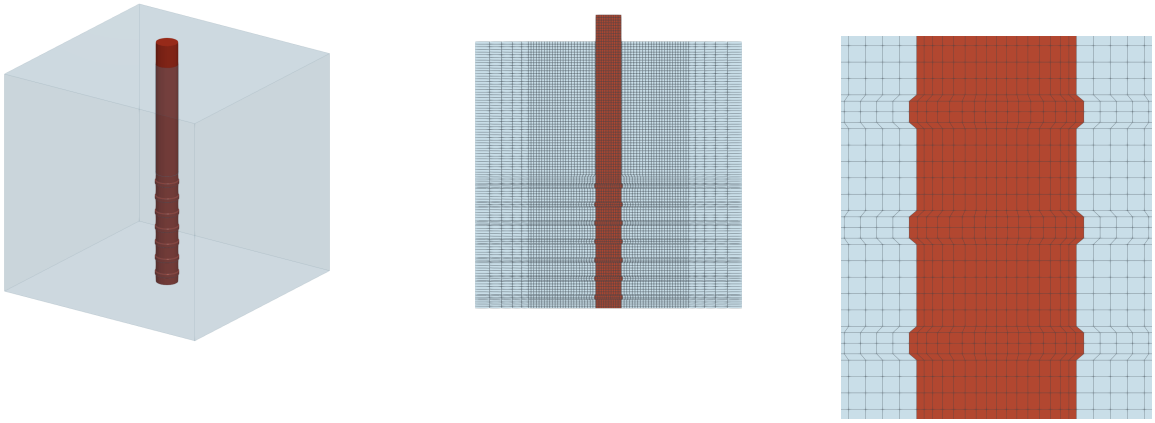
Reinforcing-bar pullout

Abaqus/Standard: CDPM2 UMAT and built-in CDP

1. Overview

This example models pullout of a bar with ring-shaped ribs using the static implicit procedure in Abaqus/Standard. Load–slip responses obtained with the CDPM2 UMAT and built-in CDP are compared using the same mesh, steel, support and contact conditions. Both analyses completed to a loaded-end displacement of 2 mm.

The example is informed by Seok's dissertation [1] and the pullout experiments of Metelli and Plizzari [2]. Ribs are represented by rings, and vertical displacement is restrained over the entire concrete top face.



Overall model | Half-model section mesh | Rib detail

Figure 1. Analysis model and mesh.

2. Model and geometry

Item	Adopted condition
Specimen / symmetry	Quarter of a 200 mm cube: $0 \le X, Y \le 100$ mm, $0 \le Z \le 200$ mm
Bar / embedment	Total length 220 mm, nominal diameter 20 mm, protrusion 20 mm above the concrete
Bonded / unbonded	Bonded $Z = 0$–100 mm; unbonded $Z = 100$–200 mm
Ribs	Core diameter 19.2 mm, crest diameter 21.0 mm, height 0.9 mm, pitch 13.9 mm
Rib positions	Seven rings, centres $Z = 8.3 + 13.9i$ mm ($i = 0, \ldots, 6$)
Width / flank	Crest width 2.55 mm, base width 4.0604 mm, flank angle 50 degrees
Unbonded zone	Smooth bar, radial gap 0.5 mm; sleeve not explicitly modelled
Elements / nodes	C3D8R; 86,152 elements (steel 6,048 / concrete 80,104), 94,930 nodes

The crest width and axial rib positions are modelling conditions adopted for this example. Experimental helical ribs are approximated by rings.

3. Material properties

Item	CDPM2	Built-in CDP
Concrete elasticity	$E = 26700$ MPa, $\nu = 0.2$	
Strength reference	$f_c = 42.7$ MPa, $f_t = 3.4$ MPa	
Viscosity parameter	$\mu = 10^{-3}$	$\mu = 10^{-4}$
Main settings	$H_p = 0.01$, $A_s = 5$, $D_f = 0.85$	Dilation angle 30 degrees, eccentricity 0.1, $f_{b0}/f_{c0} = 1.16$, $K_c = 2/3$
Damage	CDPM2 evolution law	Postpeak stress-loss ratio, capped at 0.99 in tension and compression
State variables	89	Built-in material model

Steel is elastic-perfectly plastic with $E_s = 200000$ MPa, $\nu_s = 0.3$ and yield stress 940 MPa.

About built-in CDP

CDP (Concrete Damaged Plasticity) is the concrete damage-plasticity model provided in Abaqus. It combines irreversible plastic deformation with damage-induced stiffness degradation to represent nonlinear responses associated with tensile cracking and compressive crushing. Tensile and compressive stress properties and damage are specified separately; plastic-flow parameters, including the dilation angle, define the multiaxial response [3]. CDP and CDPM2 are different constitutive models.

In this example, the tensile reference length is 2 mm. Postpeak damage is assigned separately in tension and compression using peak stress f and stress σ:

$$d = \min\{0.99, \max(0, 1 - \sigma/f)\}.$$

The complete stress and damage tables are provided in `material.inp`.

Tensile stress has a floor of 0.034 MPa (1% of tensile strength). The compression table ends at total strain 0.015 and stress 4.8912 MPa; stress remains constant beyond its endpoint. CDPM2 has no imposed damage cap of 0.99.

4. Contact, boundaries and solution controls

Item	Setting
Symmetry	$U_1 = 0$ on $X = 0$; $U_2 = 0$ on $Y = 0$, for steel and concrete
Support / loading	$U_3 = 0$ over the concrete top; $U_3 = 2$ mm at the bar top
Contact	Surface-to-surface, friction coefficient 0.5, linear penalty
Contact stiffness	Default stiffness multiplier 0.005 in Surface Behavior only; Contact Controls multiplier 1.0
Stabilization	Contact Controls stabilize=0.01; tangential factor 1.0
Static increments	Initial 0.001, step time 1, minimum 10^{-6}, maximum 1.0; limit 100000 increments
Convergence controls	$T_{\text{cont}} = T_{\text{soft}} = 10$; other controls retained in the supplied decks
Other	NLGEOM=YES, unsymmetric matrix, hourglass stiffness 55.625 MPa
Output	History every increment; field and restart output every 10 increments

Step time 1 is a numerical loading time; viscous effects depend on it. The contact stiffness multiplier is an adopted comparison setting, not a material constant.

5. Load–slip curves and results

The full-specimen load is four times the loaded-end bar reaction of the quarter model. Slip is the mean unloaded-end bar displacement relative to the mean displacement of two concrete points:

$$P = 4 \sum_{\mathrm{REB_TOP}} RF_3/1000 \quad [\mathrm{kN}], \qquad s = \overline{U_3}^{\mathrm{REB_BOTTOM}} - \frac{U_3(50,0,0) + U_3(0,50,0)}{2}.$$

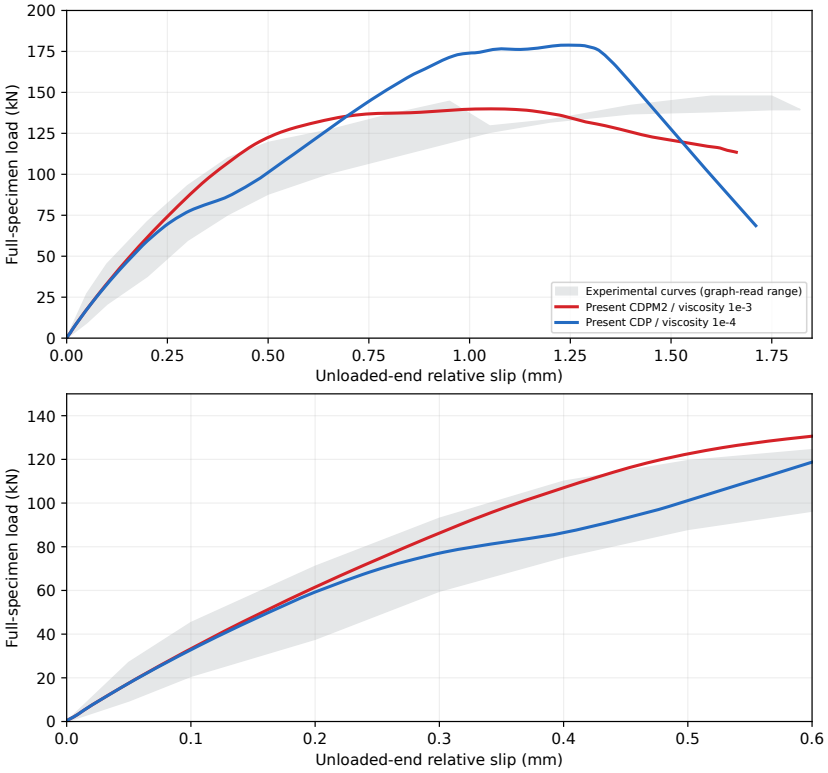


Figure 2. Overall comparison (top) and initial region (bottom). Shading is an approximate reading of experimental curves shown in Seok [1], p.61, Fig.4.8; original experiments: Metelli and Plizzari [2]. Bond stresses are converted to load using nominal area $\pi \times 20 \times 100$ mm^2. Shading is not a confidence interval or the full experimental-series range.

	CDP	CDPM2
Peak load (kN)	178.85	139.95
Slip at peak (mm)	1.2456	1.0582
Final load (kN)	68.62	113.47
Final slip (mm)	1.7104	1.6620

Both runs completed to a loaded-end displacement of 2 mm. CDP gives a higher peak load and a larger postpeak load reduction than CDPM2. The comparison uses different viscosities and multiaxial constitutive models.

6. Section contours

Maximum principal strain at a loaded-end displacement of 2 mm is compared on the half-model section.

CDP: maximum principal strain **CDPM2: maximum principal strain**

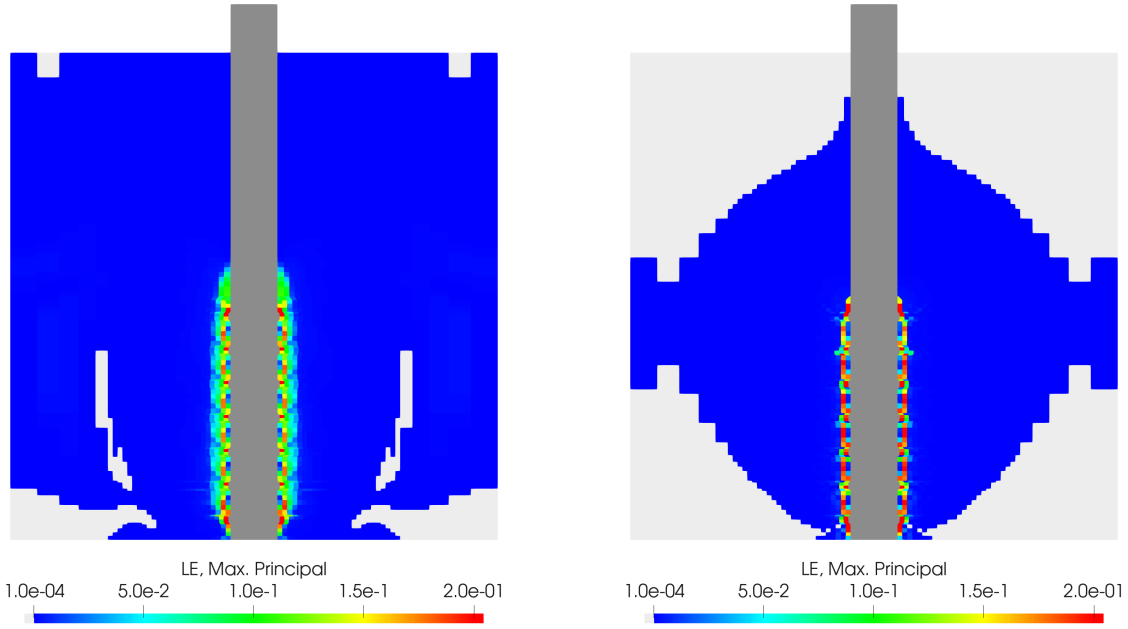


Figure 3. Maximum principal strain (LE) at a loaded-end displacement of 2 mm.

7. Supplied inputs and execution

File	Contents
`cdpm2.inp`	CDPM2 input with DEPVAR=89
`cdp.inp`, `material.inp`	Built-in CDP input and uniaxial tables
`mesh.inp`	Shared mesh, node sets and contact surfaces
`../../src/cdpm2.f90`	Shared CDPM2 UMAT and related routines
`abaqus_v6.env`	Free-form Fortran compilation option
`extract_curve.py`	ODB extraction of load and two-point-reference slip
`plot_results.py`	Comparison plot of extracted CDP/CDPM2 curves

Use Abaqus and a supported Fortran compiler, and run from the input directory. The solver is Abaqus/Standard 2026 HF0.

```
abaqus job=cdp interactive
abaqus job=cdpm2 user=../../src/cdpm2.f90 interactive
```

After analysis:

```
abaqus python extract_curve.py cdp
abaqus python extract_curve.py cdpm2
python plot_results.py
```

The output `cdp_curve.csv` or `cdpm2_curve.csv` contains time, loaded-end displacement, unloaded-end displacement, relative slip and full-specimen load. Using NumPy and Matplotlib, `plot_results.py` plots the extracted analysis curves in `comparison.png`.

CDPM2 reads initial geometry from ASCII FIL. Keep the supplied FIL requests and DEPVAR=89.

8. Sources

[1] S. Seok, *Finite Element Modeling of Bond-Zone Behavior in Reinforced Concrete*, PhD dissertation, Purdue University, December 2019. Chapter 4, Table 4.1, Figs.4.5, 4.8, 4.9. https://docs.lib.purdue.edu/dissertations/AAI30502919/

[2] G. Metelli, G. A. Plizzari, "Influence of the relative rib area on bond behaviour," *Magazine of Concrete Research*, 66(6), 277–294, 2014. Tables 1, 5, 6, Fig.2. https://doi.org/10.1680/macr.13.00198

[3] SIMULIA Abaqus 2026: Materials, Concrete Damaged Plasticity (`SIMACAEMATRefMap/simamat-c-concretedamaged.htm`); Keywords, `*CONTACT CONTROLS`, `*SURFACE BEHAVIOR`, `*DEPVAR`; Scripting, `openOdb`, history output access.

[4] Lattice, CDPM2 UMAT. https://github.com/lattice-naraoka/cdpm2-umat

Reinforcing-bar pullout: Example 2

1. Overview

Ribbed-bar pullout is analyzed with the Abaqus/Standard static implicit procedure. CDPM2 UMAT and built-in CDP are compared using the same mesh, steel, supports and contact conditions.

The central 285 mm of the concrete cylinder is bonded. Ring-shaped ribs and spiral reinforcement are modeled.

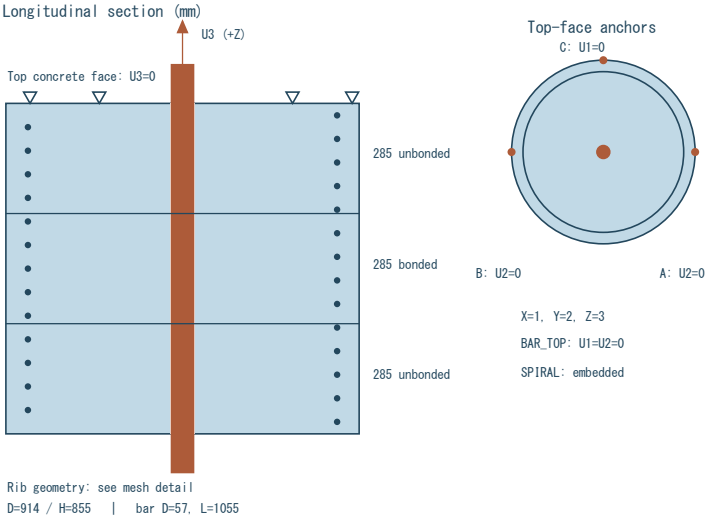


Figure 2-1. Model, supports and loading.

2. Model and geometry

Item	Adopted conditions
Specimen / symmetry	Full cylinder: diameter 914 mm, height 855 mm
Bar / bonded region	D=57 mm; L=1055 mm; bond Z=285-570 mm
Ribs	Height 2.85, crown 1.40, base 7.10, pitch 31.50 mm
Spiral	D=13 mm; outer D=813 mm; pitch=61 mm; 13 turns
Elements / nodes	C3D8R + T3D2; 421,248 elements / 441,295 nodes

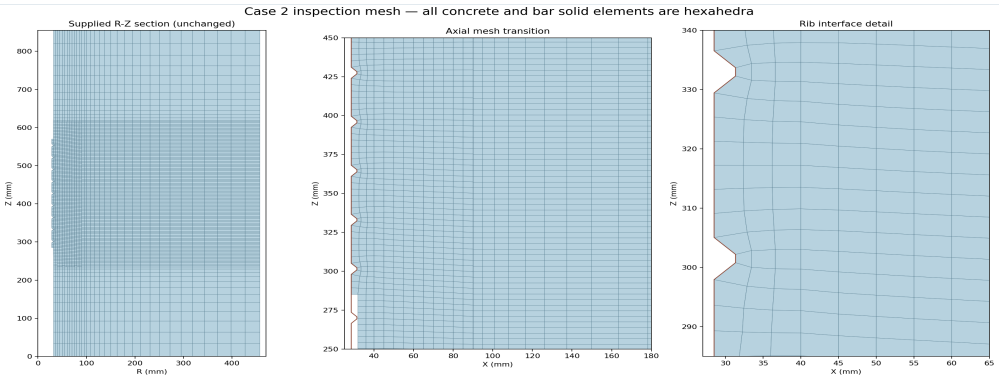


Figure 2-2. Section mesh, axial transition and rib detail.

3. Material properties

Item	CDPM2	Built-in CDP
Concrete elasticity	E=27,600 MPa; nu=0.2	E=27,600 MPa; nu=0.2
Strength reference	fc=34.5 MPa; ft=3.5 MPa	fc=34.5 MPa; ft=3.5 MPa
Viscosity	0.001	0.0001
Main parameters	Hp=0.01; As=5; Df=0.85	dilation=30 deg; ecc=0.1; fb0/fc0=1.16; Kc=2/3
Tensile softening	Gf=0.089 N/mm; ft1=1.05 MPa; wf1=0.0169524 mm; wf=0.113016 mm	Stress/damage versus displacement
State variables	89	Built-in material model

Both bar and spiral use E=200,000 MPa, nu=0.3, nominal fy=546 MPa and fu=806 MPa. A JSCE-informed assumed hardening curve uses 331 plastic data pairs, initial true yield stress 547.49058 MPa and terminal plastic strain 0.1012083347. No rupture model is included.

About built-in CDP

Tensile/compressive stress and damage are tabulated. The compression table ends at total strain 0.015, stress 2.13589 MPa and damage 0.93809. Tension uses displacement-based data with stress floor 0.035 MPa and damage cap 0.99. Full tables are in material.inp.

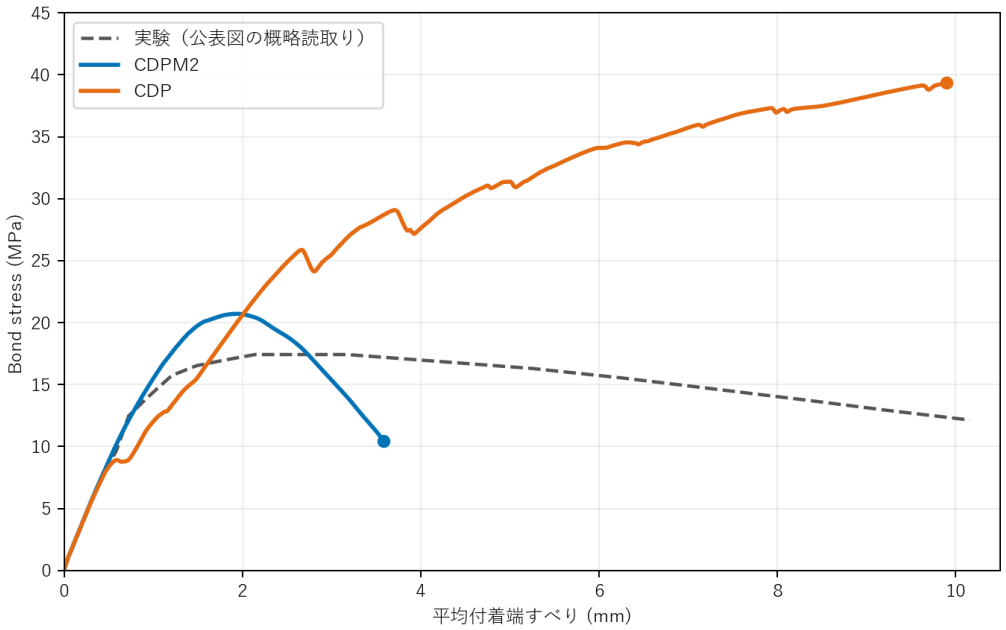
4. Contact, boundaries and solution controls

Item	Setting
Supports / loading	Concrete top U3=0; loaded bar U1=U2=0, prescribed positive U3
Rigid-body constraints	A(457,0,855): U2=0; B(-457,0,855): U2=0; C(0,457,855): U1=0
Contact / embedding	Surface-to-surface, friction 0.5, linear penalty; embedded spiral
Contact stiffness / stabilization	Surface Behavior scale=0.005; Contact Controls scale=1.0; stabilize=0.01
Static increments	initial=0.001; min=1e-6; max=1.0; max count=100000
Loading	20 mm over time 10; CDP adds time 10 toward 40 mm
Other / output	NLGEOM=YES; UNSYMM=YES; hourglass=57.5; history=1; field/restart=10

5. Bond stress-slip curves and results

Load P is the sum of loaded-bar reactions; bond stress is tau=P/(pi×57×285). Mean slip is defined below.

s = { mean U3(BAR Z285) − mean U3(CONC_BOTTOM)
+ mean U3(BAR Z570) − mean U3(CONC_TOP) } / 2 [mm]



平均付着応力 τ=P/(πdL)：d=57 mm、L=285 mm。反力の4倍換算なし。
実験：Murcia-Delso et al. (2013), Fig.7(d), Series 3 Test 1。原測定データではない。
上下付着端の相対変位を平均。

Figure 2-3. Bond stress and mean slip. Dashed line: approximate reading of Murcia-Delso et al. (2013), Fig.7(d), Series 3 Test 1.

Quantity	CDP	CDPM2
Peak bond stress (MPa)	39.34226	20.71192
Slip at peak (mm)	9.90195	1.94394
Last bond stress (MPa)	39.34226	10.43685
Last slip (mm)	9.90195	3.58574
Last actuator displacement (mm)	36.55268	4.06119

CDPM2 exhibits a post-peak decrease; CDP reaches its plotted maximum at the last point. Viscosity and multiaxial constitutive laws differ between models.

6. Section contours

Tensile damage from saved field output is shown on a longitudinal section. Actuator displacements are 4.05946 mm for CDPM2 and 27.47550 mm for CDP.

CDPM2	CDP
SDV59; U=4.05946 mm	DAMAGET; U=27.47550 mm

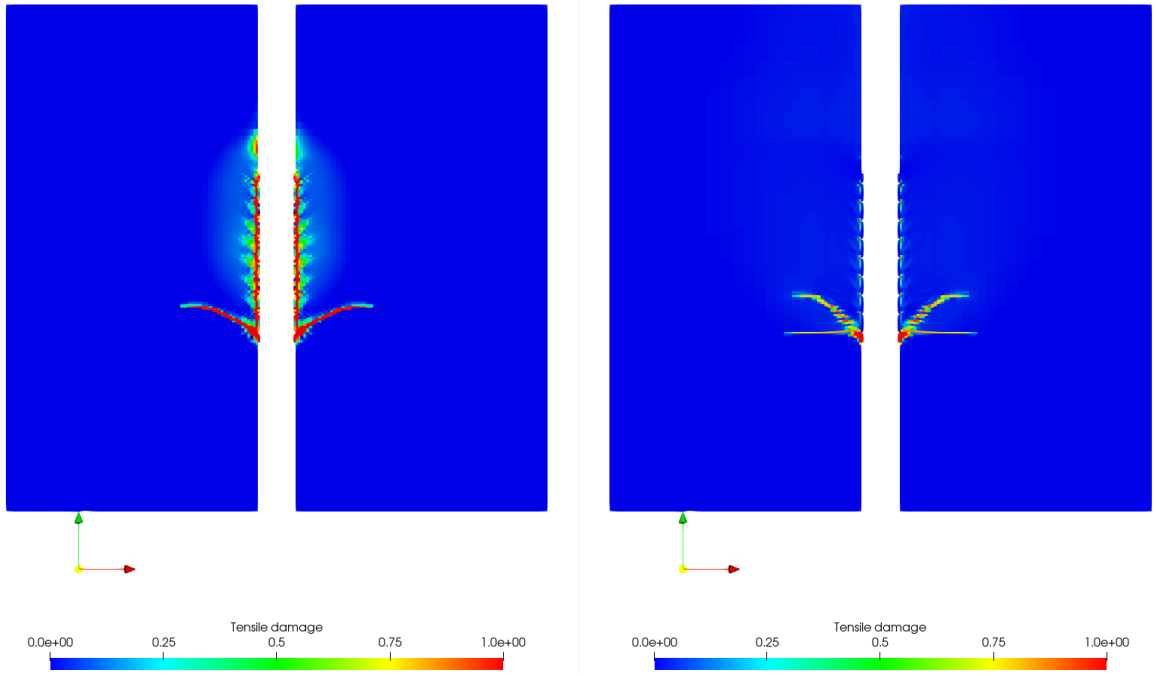


Figure 2-4. Tensile damage (left: CDPM2; right: CDP). The loading displacements are different.

7. Supplied inputs and execution

Example 2 inputs are supplied in examples/pullout/case2/.

File	Contents
cdpm2.inp	CDPM2 input (DEPVAR=89)
cdp.inp / material.inp	Built-in CDP input / uniaxial tables
mesh.inp / graph_sets.inp	Common mesh, node sets and contact surfaces
steel_plastic.inp	Bar and spiral plasticity table
../../../src/cdpm2.f90	Distributed UMAT
abaqus_v6.env	Free-form Fortran setting
extract_history.py	Extract load and mean slip from ODB

Install Abaqus and a compatible Fortran compiler, then run from the input folder. The following commands start a new analysis.

```
abaqus job=cdp interactive
abaqus job=cdpm2 user=../../../src/cdpm2.f90 interactive
```

After analysis:

```
abaqus python extract_history.py cdp
abaqus python extract_history.py cdpm2
```

The CSV contains time, lower/upper/mean slip, load and actuator displacement. Retain FIL output settings and DEPVAR=89 for reference-geometry loading.

8. Sources

[1] Murcia-Delso et al. (2013), Fig.7(d), Series 3 Test 1 (approximate experimental trace).
[2] JSCE Standard Specifications for Concrete Structures (2022), Part 10, pp.512-513, Eq.2.3.1-5 (steel curve).
[3] SIMULIA Abaqus 2026: Materials, Concrete Damaged Plasticity; SIMACAEMATRefMap/simamat-c-concretedamaged.htm.
[4] Lattice, CDPM2 UMAT. https://github.com/lattice-naraoka/cdpm2-umat