*Note: This is a description of UMAT implementation of CDPM2 provided by Peter Grassl. Last updated: 10.11.2016*

\*MAT\_‌CONCRETE\_‌DAMAGE\_‌PLASTIC\_‌MODEL

\*MAT\_‌CDPM

This is the UMAT implementation of CDPM2. CDPM2 is a damage plastic concrete model based on work published in Grassl et al. (2011, 2013) and Grassl and Jirásek (2006). This model is aimed to simulations where failure of concrete structures subjected to dynamic loadings is sought. It describes the characterization of the failure process subjected to multi-axial and rate-dependent loading. The model is based on effective stress plasticity and with a damage model based on both plastic and elastic strain measures. This material model is available only for solids.

There are a lot of parameters for the advanced user but note that most of them have default values that are based on experimental tests. They might not be useful for all types of concrete and all types of load paths but they are values that can be used as a good starting point. If the default values are not good enough the theory chapter at the end of the parameter description can be of use.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | MID | RO | E | PR | ECC | QH0 | FT | FC |
| Type | A8 | F | F | F | F | F | F | F |
| Default | none | none | none | 0.2 | AUTO | 0.3 | none | none |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | HP | AH | BH | CH | DH | AS | DF | FC0 |
| Type | F | F | F | F | F | F | F | F |
| Default | 0.5 | 0.08 | 0.003 | 2.0 | 1.0E-6 | 15.0 | 0.85 | AUTO |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | TYPE | BS | WF | WF1 | FT1 | STRFLG | FAILFLG | EFC |
| Type | F | F | F | F | F | F | F | F |
| Default | 0.0 | 1.0 | none | 0.15\*WF | 0.3\*FT | 0.0 | 0.0 | 1.0E-4 |

|  |  |
| --- | --- |
| VARIABLE | DESCRIPTION |
| MID | Material identification. A unique number or label not exceeding 8 characters must be specified. |
| RO | Mass density. |
| E | Young's modulus. If the value of the Young's modulus E is not available, it can be estimated from the uniaxial compressive strength according to, for instance, the CEB-FIP Model Code 2010. |
| PR | Poisson's ratio. |
| ECC | Eccentricity parameter.  EQ.0.0: ECC is calculated from Jirásek and Bazant (2002) as |
| QH0 | Initial hardening defined as Fci/FC where FCi is the compressive stress at which the initial yield surface is reached. Default is 0.3 |
| FT | Uniaxial tensile strength (stress). If the value of the uniaxial tensile strength is not available, the tensile strength can be estimated from the uniaxial compressive strength according to, for instance, the CEB-FIP Model Code 2010. |
| FC | Uniaxial compression strength (stress) |
| HP | Hardening parameter.  For applications without strain rate effect (STRFLG = 0) a value of HP = 0.01 is recommended. An even lower value, such as HP=0.001, is recommended for explicit analyses in which a realistic description from the transition from tension to compression is important.  Default in LSDYNA is HP = 0.5 which was the value used in Grassl et al. (2011) for strain rate dependent material response and is only recommended if STRFLG = 1. |
| AH | Hardening ductility parameter 1 (see default value in card 2) |
| BH | Hardening ductility parameter 2 (see default value in card 2) |
| CH | Hardening ductility parameter 3 (see default value in card 2) |
| DH | Hardening ductility parameter 4 (see default value in card 2) |
| AS | Ductility parameter during damage. (see default value in card 2) |
| DF | Flow rule parameter. (see default value in card 2) |
| FC0 | Rate dependent parameter. Only needed if STRFLG = 1. Recommended value is 10 MPa, which has to be entered consistently with the system of units used. |
| TYPE | Flag for tensile damage type.  EQ.0.0: Linear damage formulation  EQ.1.0: Bi-linear damage formulation  EQ.2.0: Exponential damage formulation  EQ.3.0: No damage  Default = 0.0. However, the best results are obtained with the bi-linear formulation. |
| BS | Damage ductility exponent during damage. |
| WF | Tensile threshold value for linear tensile damage formulation.  Parameter controlling tensile softening branch for exponential tensile damage formulation. For TYPE=0 (linear softening), WF = 2 GF/FT where GF is the total fracture energy. For TYPE=1 (bilinear softening), and the default values for WF1 and FT1, WF = 4.444 GF/FT. Finally, for TYPE = 2 (exponential softening), WF = GF/FT.  If the value of the fracture energy GF is not available, it can be estimated from the uniaxial compressive strength according to, for instance, the CEB-FIP Model Code 2010.  For tetrahedral meshes it is currently recommended to use 0.56 WF because the way that the element length is computed for this type of element overestimates the fracture energy.  In some cases, softening down to zero stress might result into numerical problems, which are not directly related to the constitutive model. To overcome these problems, it might be necessary to use an exponential softening law. |
| WF1 | Tensile threshold value for the second part of the bi-linear damage formulation. |
| FT1 | Tensile strength threshold value for bi-linear damage formulation. |
| STRFLG | Strain rate flag.  EQ.1.0: Strain rate dependent  EQ.0.0: No strain rate dependency. |
| FAILFLG | Failure flag.  EQ.0.0: Not active ⇒ No erosion.  GT.0.0: Active and element will erode if wt and wc is equal to 1 in FAILFLG percent of the integration points. If FAILFLG=0.60, 60% of all integration points must fail before erosion. |
| EFC | Parameter controlling compressive damage softening branch in the exponential compressive damage formulation. |
| ISOFLAG | Flag to determine if an isotropic or an anisotropic damage formulation is used. It is controlled through the sign of E. A negative value of E sets the isotropic damage formulation.  Sgn(E) = 1: ISOFLAG EQ.0.0: Anisotropic damage formulation  Sgn(E) = -1: ISOFLAG EQ.1.0: Isotropic damage formulation  Default: ISOFLAG = 0 |

History variables

*Note: these history variables might only be available in the latest development version of LS-DYNA.*

1 kappa

2 equivalent strain

3 plastic strain xx

4 plastic strain yy

5 plastic strain zz

6 plastic strain xy

7 plastic strain zy

8 plastic strain xz

9 kappa tension kdt

10 kappa tension kdt1

11 kappa tension kdt2

12 kappa compression kdc

13 kappa compression kdc1

14 kappa compression kdc2

15 damage variable tension omegaT

16 damage variable compression omegaC

17 strain rate factor

18 compression factor, alphac

19 equivalent strain - tension

20 equivalent strain - compression

21 total xx strain

22 total yy strain

23 total zz strain

24 total xy strain

25 total yz strain

26 total xz strain

27 equivalent strain w/out rate factor

Remarks:

The stress for the anisotropic damage plasticity model (ISOFLAG=0) is defined as

where ****t and ****c are the positive and negative part of the effective stress determined in the principal stress space. The scalar functions t and c are damage parameters.

The stress for the isotropic damage plasticity model (ISOFLAG=1) is defined as

The effective stress *σeff* is defined according to the damage mechanics convention as

Plasticity:

The yield surface is described by the Haigh-Westergaard coordinates: the volumetric effective stress v, the norm of the deviatoric effective stress  and the Lode angle , and it is given by

The variables *q*1 and *q*2 are dependent on the hardening variable **. The parameter *fc* is the uniaxial compressive strength. The shape of the deviatoric section is controlled by the function

where e is the eccentricity parameter (ECC). The parameter *m0* is the friction parameter and it is defined as

where *ft* is the tensile strength.

The flow rule is non-associative which means that the direction of the plastic flow is not normal to the yield surface. This is important for concrete since an associative flow rule would give an overestimated maximum stress. The plastic potential is given by

where

and

The hardening laws *q1*and *q2* control the shape of the yield surface and the plastic potential, and they are defined as

The evolution for the hardening variable is given by

It sets the rate of the hardening variable to the norm of the plastic strain rate scaled by a ductility measure which is defined below as

And finally

Damage:

Damage is initialized when the equivalent strain reaches the threshold value where the equivalent strain is defined as

Tensile damage is described by a stress-inelastic displacement law. For linear and exponential damage type the stress value and the displacement value must be defined. For the bi-linear type two additional parameters *f*t1 and *w*f1 must be defined, see figure below how the stress softening is controlled by the input parameters.

*ft*

The variable h is a mesh-dependent measure used to convert strains to displacements. The variable is called the inelastic tensile strain and is defined as the sum of the irreversible plastic strain and the reversible strain (in compression ). To get the influence of multi-axial stress states on the softening a damage ductility measure is added:

Where and are input parameters, and

The inelastic strain is then modified according:

Compressive damage is controlled by an exponential stress-inelastic strain law. Stress value and inelastic strain need to be specified, see figure below how the stress softening is controlled by the input parameters. A small value of , i.e. 1.0E-4 (default),  provides for a rather brittle form of damage.

Strain rate:

Concrete is strongly rate dependent. If the loading rate is increased, the tensile and compressive strength increase and are more prominent in tension then in compression. The dependency is taken into account by an additional variable The rate dependency is included by scaling both the equivalent strain rate and the inelastic strain. The rate parameter is defined by

Where X is continuous compression measure (= 1 means only compression, = 0 means only tension) and for tension we have

where , and For compression the corresponding rate factor is given by

where , and

**References**

P. Grassl and M. Jirásek. "Damage-plastic model for concrete failure". International Journal of Solids and Structures. Vol. 43, pp. 7166-7196, 2006.

P. Grassl, U. Nyström, R. Rempling and K. Gylltoft, "A damage-plasticity model for the dynamic failure of concrete", 8th International Conference on Structural Dynamics, Leuven, Belgium, 2011.

P. Grassl, D. Xenos, U. Nyström, R. Rempling, K. Gylltoft. "CDPM2: A damage-plasticity approach to modelling the failure of concrete". International Journal of Solids and Structures. Volume 50, Issue 24, pp. 3805-3816, 2013.