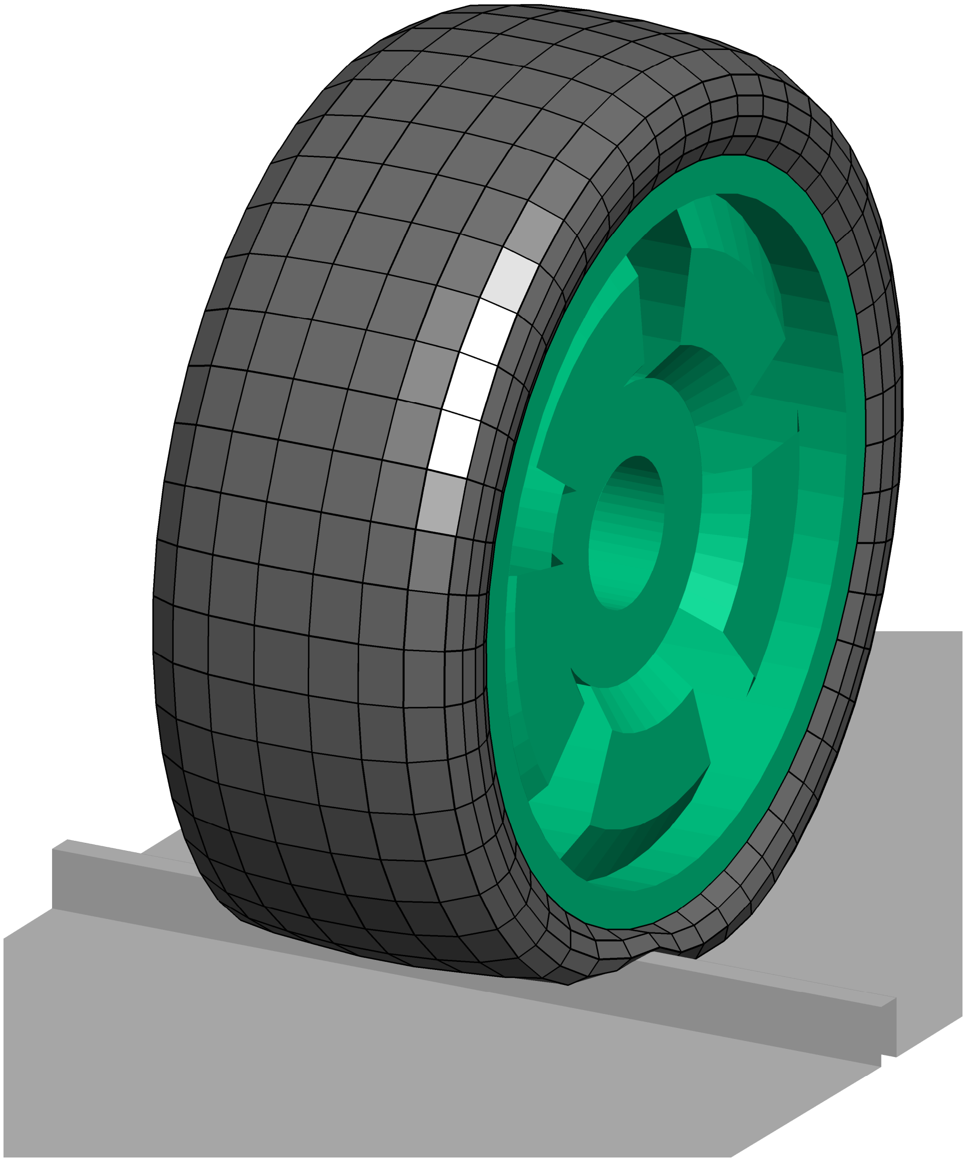
CDTire

User Manual
Version 4.2.11



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Authoring notes

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Introduction

The *Comfort and Durability Tire* is a tire model family to be used with the MBS software systems. It focuses on comfort and durability applications but also allows for handling analysis.

Remark: In the further text *Comfort and Durability Tire* will be referenced as *CDTire*.

Tire Model Background

CDTire is a tire model for passenger car and light truck tires that allows engineers to do full vehicle ride comfort and durability analysis in respective MBS software systems, taking into account tire belt dynamics and interaction with 3D road surfaces.

During the multi-body simulation CDTire computes the spindle forces and moments acting on each wheel in the model as well as the local contact forces while driving on a 3D road surface. CDTire accurately captures the vibrations in the frequency range for durability and comfort studies up to 150 Hz.

CDTire Model Family

CDTire offers 3 basic tire models

- **CDTire/3D**
- **CDTire/Realtime**
- **CDTire/MF++**

The following models are considered CDTire/Legacy and are not actively developed anymore:

- **CDTire 20, CDTire 30, CDTire 40, 2030, 2040**

However, existing model 30 parameter files can be used as they are automatically converted to CDTire/Realtime and model 40 files can be used as they are automatically converted to CDTire/3D.

The following paragraphs give some general background information to the sub-models. See the *Appendix* for a detailed description of the corresponding parameter files and their function.

CDTire/3D

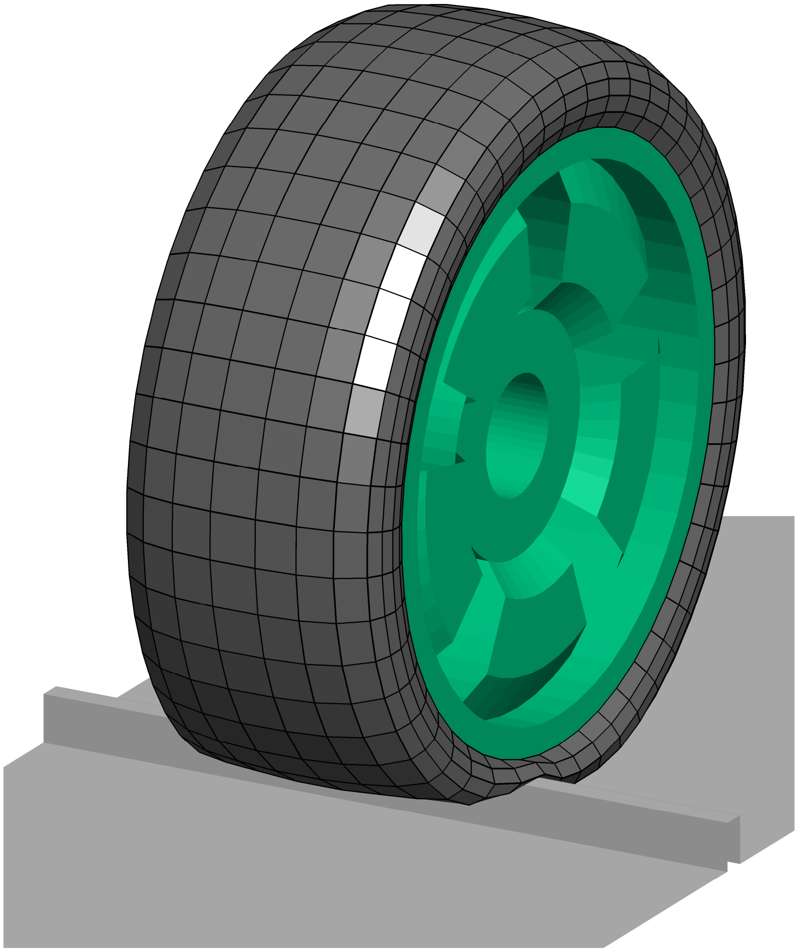

Fig. 1: CDTire/3D

Tire Model Structure:

- belt is flexible shell (default: 6x3x50 dof´s)
- both sidewalls are flexible shells (default: 8x3x50 dof´s)

Contact Formulation:

- brush type contact
- local static stick-slip ability

Performance:

- substantial effort
- $lambda_{road}$ can be arbitrary
- full obstacle enveloping

CDTire/Realtime

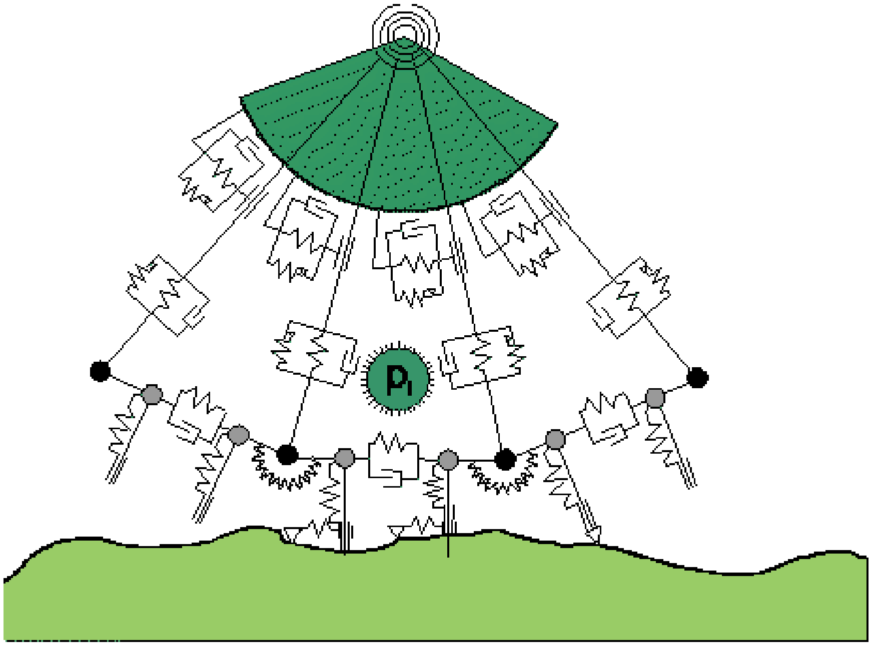

Fig. 2: CDTire/Realtime

Tire Model Structure:

- belt is flexible ring (default: 3x50 dof´s)
- sidewall is local viscoelastic foundation

Contact Formulation:

- brush type contact
- local static stick-slip ability

Performance:

- hard real time capable
- road surface wavelength $lambda_{road}$ can be arbitrary in tire in-plane direction
- restriction: only in-plane obstacle enveloping, as lateral extension of in-plane tire-road intersection is considered constant for each tire

CDTire/MF++

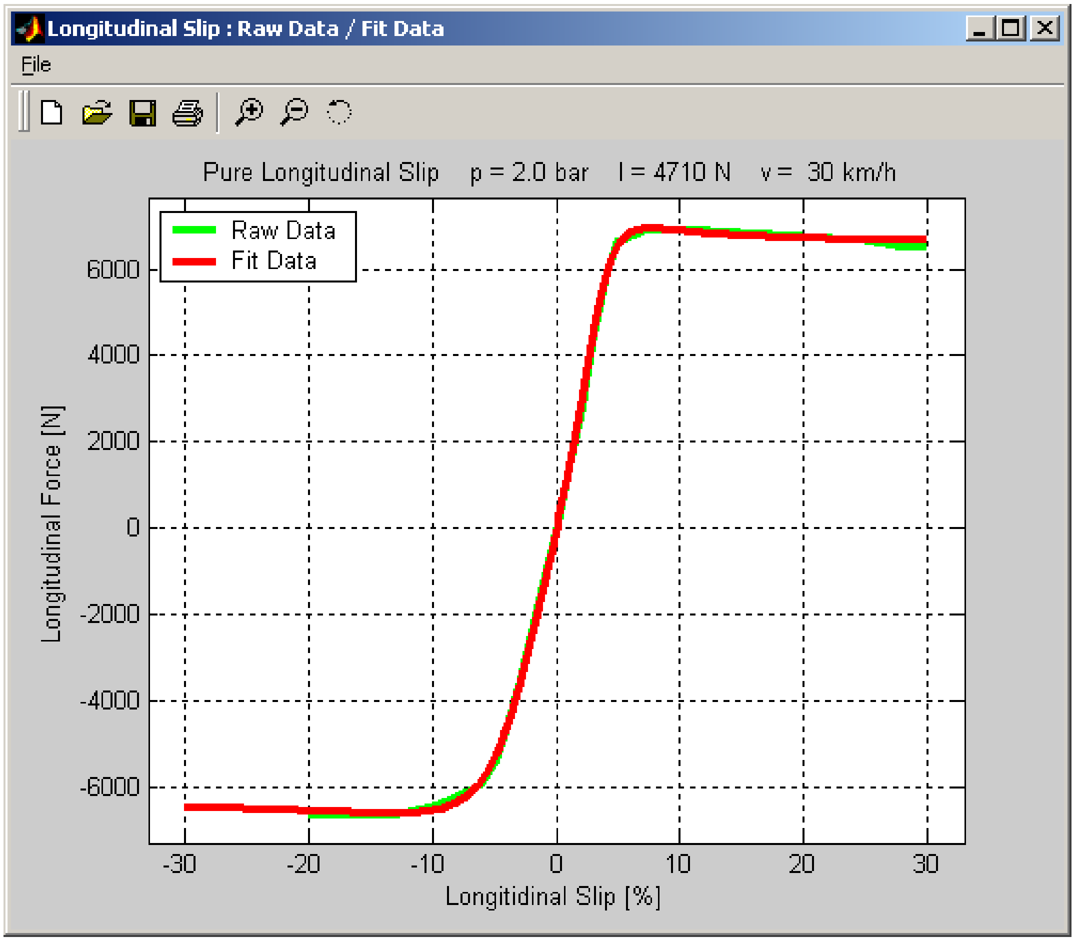

Fig. 3: CDTire/MF++

Tire Model Structure:

- MF 5.2 / PAC2002
- Coupled with CDTire/Thermal

Contact Formulation:

- Estimation of contact patch shape, location and stick/slip zones
- Temperature dependent friction and grip levels

Performance:

- hard real time capable

Road Surface Models

Technically, the Road Surface Model is a software library through which *CDTire* can interrogate road surfaces in order to sense contact. Three mechanisms for road surface definitions are supported with the Road Surface Model:

- CDTire internal road surface models (RSM 1000, 1002, 1008, 2000, 3000)
- User defined road surface model (RSM 1100)
- MBS dependent road surface models may be available, see the corresponding *CDTireMBSManua*l for more information.

CDTire road surfaces models (RSMs)

See the chapter ***Model Usage*** for detailed information on the single models.

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MBS road surfaces models (RSMs)

Some MBS systems allow CDTire to utilize their own road surface models. See the respective ***CDTire MBS Guide*** for detailed information on the these models and how to use them.

Model Implementation

The implementation is done by using a dedicated element to include *CDTire* in your vehicle or testrig model.

Modeling with CDTire

The *CDTire* element is a dedicated element in the modeling process and supports various commercially available MBS software packages :

- Altair MotionSolve
- IPG CarMaker
- LMS Samtech Samcef Mecano
- Siemens Simcenter 3D Motion
- MATLAB / Simulink
- Mechanical Simulation CarSim
- MSC ADAMS
- Dassault Systemes SIMPACK
- VI-grade VI-CarRealTime

Please see the *CDTire MBS Guide* documentation of the specific guides on how to model with CDTire.

Model Usage

To include the CDTire in a MBS model also road data is required. This data can, in the simplest form, describe a plain surface without any obstacles or tracks. More complex data give an analytical description of a road surface with obstacles or tracks, digitized measured data, a combination of those or of a drum surface.

CDTire supports several road surface models:

Road Surface Model	Surface Type
1000	parametric road surface description
1002	rolling drum with or without a cleat
1008	3D surface
1100	User road model (ADAMS only)
2000	parametric and digitized road data
3000	OpenCRG® (1.1.1) road data

Road Surface Model 1000

The Road Surface Model 1000 is adapted for an analytical description of the road surface. A number of different obstacle types and tracks are available to model the road. It will generate a surface Z(X,Y) with respect to the coordinate system representing the surface origin as defined in the MBS model (P5).

A road definition file for the Road Surface Model 1000 is structured as follows:

- **Header**: This part specifies the additional translation and the used data type (obstacles, equidistant tracks or non-equidistant tracks).
- **Data Part**: For each obstacle or track the corresponding data is defined

Header (Road Surface Model 1000)

```
# HEADER ROAD MODEL 1000
# X0_ROAD    Y0_ROAD    Z0_ROAD    MU_ROAD
  200.0      200.0      100.0      0.9
# DATA TYPE: (2, 3 OR 4)
  2
```

The first line is a comment line starting with a hash (#). You may use it for specifying a short description or general comment to the road definition file. This line is required but all contents will be ignored by *CDTire*.

The second and the fourth lines are comment lines starting with a hash (#), too. Here you should enter "placeholders" for the data in the following lines. *CDTire* ignores these lines but the file will be easier to read for all users.

The third line contains the data defining the additional translation. The data type is defined by the entry in the fifth line.

Additional Translation

You may define a translation of the road coordinate system (X0) from the road origin marker (P5) of the MBS model.

Fig. 4: additional translation

The additional translation is defined in the third line:

```
Line 1: # HEADER ROAD MODEL 1000
Line 2: # X0_ROAD    Y0_ROAD    Z0_ROAD    MU_ROAD
Line 3:   200.0      200.0      100.0      0.9
```

with

X0_ROAD	Translation in x-direction
Y0_ROAD	Translation in y-direction
Z0_ROAD	Translation in z-direction
MU_ROAD	friction coefficient road

The parameters **X0_ROAD**, **Y0_ROAD** and **Z0_ROAD** determine the position of the subsequent definitions with respect to the coordinate system representing the surface origin as defined in the MBS model.

The friction coefficient of the road defines the friction of the defined plane except for all explicitly defined parts like tracks or obstacles, as these must specify their own friction coefficient.

Data Type

The data type defines the surface structure in general. It is given in the 5th line of the road definition file:

```
Line 1: # HEADER ROAD MODEL 1000
Line 2: # X0_ROAD    Y0_ROAD    Z0_ROAD    MU_ROAD
Line 3:   200.0      200.0      100.0      0.9
Line 4: # DATA TYPE:  (2, 3 OR 4)
Line 5:   2
```

with

DATA TYPE	2 = equidistant track data
	3 = non-equidistant track data
	4 = matrix track data

The previously available **Data Type 1** road surface description is not supported anymore and will generate an error message.

Data Part (Road Surface Model 1000)

Depending on the data type defined in the header the data part contains one or more definitions of either obstacles or equidistant tracks or non-equidistant tracks. Mixing the data types is not possible.

Equidistant Track Data (DATA TYPE 2)

This is the preferred data type to construct track surfaces Z(X) on equidistant data (**DATA TYPE** = 2).

Fig. 5: Road Surface Model 1000: equidistant track data

The direction of the track will be the x-direction of the coordinate system representing the surface origin as defined in the MBS model. Interpolation of the track data will be linear.

There can be several tracks defined in one file. Therefore the header of a road definition file for equidistant track data contains two additional lines:

```
Line 6: # NTRACKS
Line 7:   3
```

with

NTRACKS	total number of tracks

For each of the **NTRACKS** tracks a body definition follows. If these tracks overlap, *CDTire* will generate a runtime error once it tries to evaluate a multiply defined surface point. The body of a track consists of 2 + **NDATA** lines:

```
# NDATA  X0_TRACK  Y0_TRACK  HALF_WIDTH  DX    MU_TRACK
  4      0.0       0.0       300.0       10.0  1.0
  0.0
  10.0
  10.0
  0.0
```

with

NDATA	number of data points of the track
X0_TRACK	track origin x-coordinate with respect to the road data origin
Y0_TRACK	track origin y-coordinate with respect to the road data origin
HALF_WIDTH	half width of the track
DX	equidistant spacing Δx of the track data
MU_TRACK	friction coefficient of the track surface
Line 10 ... Line 9 + **NDATA**	these lines contain the z data of the single tracks (local hight)

The total width of the track is 2***HALF_WIDTH**, i.e. **HALF_WIDTH** is applied in the positive and the negative Y-direction, starting at **Y0_TRACK**.

Line 3 starts with the first data value. This value does not need to be zero, allowing for discontinuous surfaces. All further data must be on consecutive lines, one value each, as specified by NDATA.

See the chapter ***Example for Equidistant Track Data (Data Type 2)*** in the Appendix for a detailed example.

Non-equidistant Track Data (DATA TYPE 3)

This data type (**DATA TYPE** = 3) is used to construct track surfaces with non-equidistant data (based on pairs of (X,Z) data). For certain types of street profiles the use of this data type would be much more efficient than equidistant data (e.g. a ramp). The direction of the track is the same as for the equidistant data. Again, several tracks can be defined in one file.

As for equidistant track data, the header is extended by the lines

```
Line 6: # NTRACKS
Line 7:   3
```

with

NTRACKS	total number of tracks

For each of the **NTRACKS** tracks a body definition follows. If these tracks overlap, *CDTire* will generate a runtime error once it tries to evaluate a multiply defined surface point. The body of a track consists of 2 + **NDATA** lines:

```
# NDATA  X0_TRACK  Y0_TRACK  HALF_WIDTH  MU_TRACK
  3      0.0       0.0       300.0       1.0
  0      0
  30000  1000
  50000  0
```

with

NDATA	number of data points of the track
X0_TRACK	track origin x-coordinate with respect to the road data origin
Y0_TRACK	track origin y-coordinate with respect to the road data origin
HALF_WIDTH	half width of the track
MU_TRACK	friction coefficient of the track surface
Line 10 ... Line 9 + **NDATA**	these lines contain the x and z data of the single tracks

See the chapter ***Example for Non-Equidistant Track Data (Data Type 3)*** in the Appendix for a detailed example.

Matrix Track Data (DATA TYPE 4)

This data type (**DATA TYPE** = 4) is used to construct track surfaces with matrix data. The direction of the track is the same as for the equidistant data. Again, several tracks can be defined in one file.

```
Line 6: # NTRACKS
Line 7:   3
```

with

NTRACKS	total number of tracks

For each of the **NTRACKS** tracks a body definition follows. If these tracks overlap, *CDTire* will generate a runtime error once it tries to evaluate a multiply defined surface point. The body of a track consists of 2 + **NDATA** lines:

```
# NX     NY     X0     Y0     DX     DY     MU     ZSCALE    Z0
  3      5    -10.0 -10.0   10.0   5.0    0.9    1.0       0.0
  6.0   6.0   6.0   6.0   6.0
  6.0   3.0   0.0   3.0   6.0
  6.0   6.0   6.0   6.0   6.0
```

with

NX	number of matrix rows of the track matrix
NY	number of matrix columns of the track matrix
X0	track origin x-coordinate with respect to the road data origin (upper left point)
Y0	track origin y-coordinate with respect to the road data origin (upper left point)
DX	(signed) spacing x direction (between rows)
DY	(signed) spacing y direction (between columns)
MU	friction coefficient of the track matrix
ZSCALE	Scaling of matrix values (z values)
Z0	Additive offset of matrix values (z values)

Road Surface Model 1002

The Road Surface Model 1002 adapts an analytical description of a drum surface. A number of different obstacle types and tracks are available to model the drum. It will generate a surface dR(phi,Y) with respect to the coordinate system representing the surface origin as defined in the MBS model (P5).

A road definition file for the Road Surface Model 1002 is structured as follows:

- **Header**: This part specifies the additional translation and the used data type (obstacles, equidistant tracks or non-equidistant tracks).
- **Data Part**: For each obstacle or track the corresponding data is defined

Header (Road Surface Model 1002)

```
# DESCRIPTION LINE
# RADIUS_DRUM      MU_DRUM     PERIODIC
  1000.0           1.0         1
# SURFACE TYPE
  1
```

The first line is a comment line starting with a hash (#). You may use it for specifying a short description or general comment to the drum definition file. This line is required but all contents will be ignored by *CDTire*.

The second and fourth lines are comment lines starting with a hash (#), too. Here you should enter "placeholders" for the data in the following lines. *CDTire* ignores these lines but the file will be easier to read for all users.

The third line contains the data defining the drum surface without any obstacles or data. It consists of the radius of the drum (in [mm]) and the friction coefficient (in [1]). A third parameter is the periodic flag, and if set obstacles appear with every revolution of the drum surface. If not set, the obstacle will appear only once (depending on S_0 settings). The fifth line contains the type of obstacle data.

```
Line 1: # DESCRIPTION LINE
Line 2: # RADIUS_DRUM      MU_DRUM     PERIODIC
Line 3:   1000.0           1.0         1
Line 4: # SURFACE TYPE
Line 5:   2
```

with

RADIUS_DRUM	drum radius in [mm]
MU_DRUM	friction coefficient drum surface outside obstacle data
PERIODIC	repeat cleat (1) or only once (0)
SURFACE TYPE	
	2 = with rectangular cleat
	3 = with chamfered cleat
	4 = matrix data

Fig. 6: Road Surface Model 1002: rolling drum

Header (Road Surface Model 1002)

With R4.2.7, there are 3 surface types to construct drum surfaces with.

Rectangular cleat (SURFACE TYPE 2)

The road definition file for a drum surface with any rectangular cleat (SURFACE TYPE 2) has the following structure:

```
# DESCRIPTION LINE
# RADIUS_DRUM       MU_DRUM     PERIODIC
  1000.0            1.0         1
# SURFACE TYPE
  2
# H        W        S_0        PHI         MU_CLEAT
  10.0     20.0    -2522.2     90.0           0.8
```

with

H	height [mm] of cleat
W	width [mm] of cleat (length of cleat is infinite)
S_0	arc length[mm] from top of drum to cleat origin - for PERIODIC_FLAG = 1, this must be -RADIUS_DRUM*PI < S_0 < RADIUS_DRUM*PI
PHI	direction angle of cleat, measured from wheel plane, transversal cleat is 90°

MU_CLEAT	friction coefficient on cleat

Ramped / trapezoid cleat (SURFACE TYPE 3)

The road definition file for a drum surface with any ramped or trapezoid cleat (SURFACE TYPE 3) has the following structure:

```
# DESCRIPTION LINE
# RADIUS_DRUM     MU_DRUM    PERIODIC
  1000.0          1.0        1
# SURFACE TYPE
  3
# H      W1     W2     W3      S_0      PHI      MU_CLEAT
  10.0   20.0   40.0   20.0   -2522.2   90.0       0.8
```

with

H	height [mm] of cleat
W1	width (arclength) [mm] of leading ramp
W2	width (arclength) [mm] of leading ramp
W3	width (arclength) [mm] of trailing ramp
S_0	arclength [mm] from top of drum to cleat origin - for PERIODIC_FLAG = 1, this must be -RADIUS_DRUM*PI < S_0 < RADIUS_DRUM*PI
PHI	direction angle of cleat, measured from wheel plane
MU_CLEAT	friction coefficient on cleat

Matrix data (SURFACE TYPE 4)

The road definition file for a drum surface with any equidistant grid or matrix data dR(phi,y) (SURFACE TYPE 4) has the following structure:

```
# DESCRIPTION LINE
# RADIUS_DRUM     MU_DRUM    PERIODIC
  1000.0          1.0        1
# SURFACE TYPE
  4
# NPHI  NY  PHI0  DPHISEG  Y0     DY  MU   SCALE  RADIUSOFFSET
  4     2   0.0   3.438   -200.0  400 0.8  1.0    0.0
10.0  10.0
20.0  20.0
20.0  20.0
10.0  10.0
```

with

NPHI	number of circumferential data points

NY	number of lateral (axial) data points
PHI0	Starting angle [deg] of data segment, -180 < PHI0 < 180
DPHISEG	angular segment range [deg] of data, 360° for full drum
Y0	starting lateral coordinate [mm] of data
DY	Lateral segment range [mm] of data, range is [Y0,Y0+DY]
MU	friction coefficient on data
SCALE	scaling coefficient for radial data
RADIUSOFFSET	Offset value [mm]
DATA	NPHI rows, NY columns

Above example makes up a trapeze.

All lines starting with a hash (#) are comment files used to define placeholders for the data in the following lines. Even if *CDTire* will skip over them, these lines are required. Do not delete them!

Road Surface Model 1008

This road surface model is the CDTire implementation of the 3D method of MSC Adams .rdf data files. Some MBS systems can also visualize this road format in their respective Pre-/Postprocessor. This documentation lists only the required data format to work with CDTire - for visualization support of MBS systems, please refer to the respective MBS documentation.

Data structure and format

The data file is based on section / keyword format. A valid section line contains the name of the section is square brackets. A valid keyword line contains the name of the keyword, followed by the '=' character, followed by the value. A valid CDTire RSM1008 file is shown here:

```
[MODEL]
METHOD = '3D'

[UNITS]
LENGTH = 'MM'

[OFFSET]
X = 100.0
Y = 200.0
Z = -10.0
```

```
[NODES]
NUMBER_OF_NODES  = 4
{ node   x_value  y_value  z_value }
  1      -10.0    -200.0   10.0
  2       10.0    -200.0   10.0
  3       10.0     200.0   10.0
  4      -10.0     200.0   10.0

[ELEMENTS]
NUMBER_OF_ELEMENTS  = 2
{ node_1  node_2  node_3  u }
  1       2       3       0.8
  1       3       4       0.8
```

The following format details may only be valid for the CDTire implementation of .rdf files:

- Section names, keyword names and strings are case insensitive. All of “METHOD”, “method”, “Method” are the same valid keyword.
- Supported units are “MM” (millimeter), “CM” (centimeter), and “M” (meter)
- In node and element section, a comment line containing a left brace (curly) bracket indicates that the next line starts with the respective data matrix (nodes or elements). The successive NUMBER_OF_xxx lines must contain valid line data for each line.

Road Surface Model 2000

CDTire Setup for Road Surface Model 2000

CDTire needs to be set up for road surface type "2000" in order to make use of the Road Surface Model.

In order to run *CDTire* on road data, following set of files is required in the

In order to run *CDTire* on road data, following set of files is required in the directory referred to in the CDTire setup:

- a global definition file that defines the boundaries of the track **`MasterRectangle.h`**
- a surface type classification file **`SurfacType.h`** that defines the friction coefficient for the different surface types as referred in the road data files
- a set of "macropatch" header files named **`MP_0_0.h`**, **`MP_0_1.h`** etc.
- (when applicable) a set of "macropatch" binary data files named **`MP_0_0.d`**, **`MP_0_1.d`** etc.
- (when applicable) a set of parametric road description files

---

Note : the mention "when applicable" relates to the fact that a track definition for CDTire may be defined either through digitized data only, parametric description files only, or a mix of both.

IMPORTANT : all the files mentioned above are ***strictly required***, and need to adhere to the specified naming and format conventions. The format of the needed header files is explained in the following sections.

The fundamental idea behind the *Road Format* concept is that any track will be described in a rectangular grid ; which has three levels of discretization :

- a "master rectangle" that envelopes the complete track
- a series of "macropatches" (typically size 10 x 10 m) defined inside this master rectangle
- a series of "micropatches" per macropatch (typical size 0.5 x 0.5 m)
- a rectangular mesh in each micropatch (grid size typically 5 x 5 mm), where per grid point in the mesh the track Z-coordinate has been measured and stored

MasterRectangle.h

The structure of the file **`MasterRectangle.h`** is:

`version indicator`	actual value : v002 (string)
`comment`	string(s) of arbitrary length beginning with #
`platform-flag`	specifies platform where binary data have been written (integer) 1→Unix, 2→Windows NT, 3→SGI IRIX
`. . .`	
`Xoff Yoff Zoff`	real altitude and offset of left lower corner of the Master Rectangle (double)
`indicator`	to read the Macro-patches column-wise (1 char: c)
`rows <space> columns`	number of rows and columns of Macro-patches (long)
`width <space> height`	width and height of a Macro patch (double)
`units`	string max 17 characters – reserved for future use

Example for MasterRectangle.h

```
v002
# Master rectangle definition for Track A
2
-100.000 -100.000 15.000
c
7 1
10000.000 10000.000
mm
```

MacroPatch header files

The structure of the macropatch files **`MP_0_0.h`**, **`MP_0_1.h`**, …is:

File entry	**Meaning**
`Macropatch column_nr row_n`	
`{`	
`version indicator`	actual value : v002 (string)
`comment`	string(s) of arbitrary length beginning with #

File entry	**Meaning**
`platform-flag`	specifies platform where binary data have been written (integer) 1→Unix, 2→Windows NT, 3→SGI IRIX
`Zoff`	z-Position of left lower corner relative to origin of Master-rectangle (double)
`columns <space> rows`	number of columns and rows of micro-patches (long)
`width <space> height`	width and height in mm of a micro-patch (double)
`indicator`	to read the micro-patches column-wise (1 char: c)
`}`	
`Micropatch 0 0`	header of micro patch section 0 0
`<header info>`	header info of micro patch section 0 0
`Micropatch 0 1`	header of micro patch section 0 1
`<header info>`	header info of micro patch section 0 1
`Micropatch 0 2`	header of micro patch section 0 2
`<header info>`	header info of micro patch section 0 2
`. . .`	

The format of the micro patch sections in the macro patch header files depends on the type of road description:

- off-road

File entry	**Meaning**
`Micropatch micro_column_nr micro_row_n`	micro patch header
`datatype`	0 -> off road (integer)

- digitized

File entry	**Meaning**
`Micropatch micro_column_nr micro_row_n`	micro patch header
`datatype`	1 -> digitized (integer)
`trackclassification`	refers to a classification number in surface classification file (integer)
`width <space> height`	width and height in mm of an element (double)
`lines_h <space> lines_v`	number of grid lines horizontally and vertically (integer)
. . .	
`byte number`	byte number of the first micro-patch identifier index in the data file (unsigned integer)
`indicator`	to read the micro-patches column-wise (1 char: c)
. . .	
`tiretype_proposed`	20 | 30 | 40 (integer)
`flag`	reserved for future use (integer)

- parameterized

File entry	**Meaning**
`Micropatch micro_column_nr micro_row_n`	micro patch header
`datatype`	2 -> parameterized (integer)
`trackclassification`	refers to a classification number in surface classification file (integer)
`filename`	Filename withozt pathname for data specification (string)
`tiretype_proposed`	20 | 30 | 40 (integer)
`flag`	reserved for future use (integer)

Example for a MacroPatch header file

The following example contains the 3 types of micropatches. This file shows only the first and second column.

```
Macropatch 0 0
{
 v002
# Example
 2
 -10.0000
 20 20
 500.000 500.000
 c
}
Micropatch 0 0
1
1
5.000 5.000
101 101
0
c
20
2030
Micropatch 0 1
1
1
5.000 5.000
101 101
40812
c
20
2030
Micropatch 0 2
1
1
5.000 5.000
101 101
81624
c
20
2030
Micropatch 0 3
1
1
5.000 5.000
101 101
122436
c
```

```
20
2030
Micropatch 0 4
1
1
5.000 5.000
101 101
163248
c
20
2030
Micropatch 0 5
1
1
5.000 5.000
101 101
204060
c
20
2030
. . .
Micropatch 0 9
2
1
ParametricFile.h
20
2030
Micropatch 0 10
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1
ParametricFile.h
20
2030
Micropatch 0 11
2
1
ParametricFile.h
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Micropatch 0 12
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ParametricFile.h
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. . .
Micropatch 1 7
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```
1
5.000 5.000
101 101
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Micropatch 1 8
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5.000 5.000
101 101
693804
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Micropatch 1 9
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Micropatch 1 10
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Micropatch 1 11
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Micropatch 1 12
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Micropatch 1 13
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Micropatch 1 14
0
Micropatch 1 15
0
Micropatch 1 16
0
Micropatch 1 17
0
Micropatch 1 18
0
Micropatch 1 19
0
```

Surface type classification file

This file contains an ascii table defining the friction coefficient that corresponds to the surface types as specified in each micro patch header file.

Example for a surface type classification file

```
17           →   Maximum class number defined in the file
0<tab>1.00   →   Surface class  <tab>  friction coefficient
5<tab>1.01   →   Surface class  <tab>  friction coefficient
12<tab>1.05  →   …
13<tab>1.1   →   …
17<tab>1.15  →   …
```

Customizing CDTire

Even though *CDTire* tries to present a setup in a plug-and-play fashion, there are several considerations for a successful simulation that cannot be tuned automatically. These include structural discretization, integrator tuning and inflation pressure.

For more information on

- Structural discretization and inflation pressure refer to the chapters in the Appendix:
  - ***Tire Parameter Files for CDTire/MF++***
  - ***Tire Parameter Files for CDTire/Realtime*** and
  - ***Tire Parameter Files for CDTire/3D***

Appendix

Tire Parameters

The following paragraphs explain the parameter files for the tire models *CDTire/MF++*, *CDTire/Realtime* and *CDTire/3D* in detail. For each tire model a listing of the corresponding parameter file and explanations to the single parameters are given.

Tire Parameter File - CDTire/MF++

The following listing shows the input file for a tire as used in the tire model *CDTire/MF++*:

```
 [UNITS]
LENGTH = 'meter'
FORCE = 'newton'
ANGLE = 'radians'
MASS = 'kg'
TIME = 'second'

[MODEL]
LONGVL = 16.6                $Measurement speed
THERMAL_MODEL_FLAG = 0
VELOCITY_TRESHOLD = 0.5      $Lower cut off velocity

[DIMENSION]
UNLOADED_RADIUS = 0.312      $Free tyre radius
WIDTH = 0.195                $Nominal section width of tyre
ASPECT_RATIO = 0.65          $Nominal aspect ratio
RIM_RADIUS = 0.19            $Nominal rim radius
RIM_WIDTH = 0.1524           $Rim width

[VERTICAL]
VERTICAL_STIFFNESS = 2e+005  $Tyre vertical stiffness
VERTICAL_DAMPING = 0         $Tyre vertical damping
BREFF = 6.1                  $Low load stiffness e.r.r.
DREFF = 0.45                 $Peak value of e.r.r.
FREFF = 0.01                 $High load stiffness e.r.r.
FNOMIN = 4000                $Nominal wheel load

[PARAMETER]
```

```
VERTICAL_STIFFNESS = 2e+005     $Tyre vertical stiffness

[LONG_SLIP_RANGE]
KPUMIN = -1.5                   $Minimum valid wheel slip
KPUMAX = 1.5                    $Maximum valid wheel slip

[SLIP_ANGLE_RANGE]
ALPMIN = -1.5708                $Minimum valid slip angle
ALPMAX = 1.5708                 $Maximum valid slip angle

[INCLINATION_ANGLE_RANGE]
CAMMIN = -0.26181               $Minimum valid camber angle
CAMMAX = 0.26181                $Maximum valid camber angle

[VERTICAL_FORCE_RANGE]
FZMIN = 200                     $Minimum allowed wheel load
FZMAX = 9000                    $Maximum allowed wheel load

[SCALING_COEFFICIENTS]
LFZO = 1       $Scale factor of nominal (rated) load
LCX = 1        $Scale factor of Fx shape factor
LMUX = 1       $Scale factor of Fx peak friction coefficient
LEX = 1        $Scale factor of Fx curvature factor
LKX = 1        $Scale factor of Fx slip stiffness
LHX = 1        $Scale factor of Fx horizontal shift
LVX = 1        $Scale factor of Fx vertical shift
LGAX = 1       $Scale factor of camber for Fx
LCY = 1        $Scale factor of Fy shape factor
LMUY = 1       $Scale factor of Fy peak friction coefficient
LEY = 1        $Scale factor of Fy curvature factor
LKY = 1        $Scale factor of Fy cornering stiffness
LHY = 1        $Scale factor of Fy horizontal shift
LVY = 1        $Scale factor of Fy vertical shift
LGAY = 1       $Scale factor of camber for Fy
LTR = 1        $Scale factor of Peak of pneumatic trail
LRES = 1       $Scale factor for offset of residual torque
LGAZ = 1       $Scale factor of camber for Mz
LXAL = 1       $Scale factor of alpha influence on Fx
LYKA = 1       $Scale factor of alpha influence on Fx
LVYKA = 1      $Scale factor of kappa induced Fy
LS = 1         $Scale factor of Moment arm of Fx
LSGKP = 1      $Scale factor of Relaxation length of Fx
LSGAL = 1      $Scale factor of Relaxation length of Fy
LGYR = 1       $Scale factor of gyroscopic torque
LMX = 1        $Scale factor of overturning couple
LVMX = 1       $Scale factor of Mx vertical shift
LMY = 1        $Scale factor of rolling resistance torque
```

```
[LONGITUDINAL_COEFFICIENTS]
PCX1 = 1.839     $Shape factor Cfx for longitudinal force
PDX1 = 1.1387    $Longitudinal friction Mux at Fznom
PDX2 = -0.11999  $Variation of friction Mux with load
PDX3 = -2.2142e-005 $Variation of friction Mux with camber
PEX1 = 0.62727   $Longitudinal curvature Efx at Fznom
PEX2 = -0.12336  $Variation of curvature Efx with load
PEX3 = -0.03448  $Variation of curvature Efx with load squared
PEX4 = -1.5066e-005 $Factor in curvature Efx while driving
PKX1 = 18.886    $Longitudinal slip stiffness Kfx/Fz at Fznom
PKX2 = -3.988    $Variation of slip stiffness Kfx/Fz with load
PKX3 = 0.21542   $Exponent in slip stiffness Kfx/Fz with load
PHX1 = -0.00033912 $Horizontal shift Shx at Fznom
PHX2 = -8.5877e-006 $Variation of shift Shx with load
PVX1 = -4.638e-006 $Vertical shift Svx/Fz at Fznom
PVX2 = 1.9874e-005  $Variation of shift Svx/Fz with load
RBX1 = 5.9945    $Slope factor for combined slip Fx reduction
RBX2 = -8.2609   $Variation of slope Fx reduction with kappa
RCX1 = 1.07816   $Shape factor for combined slip Fx reduction
REX1 = 1.644     $Curvature factor of combined Fx
REX2 = -0.0064359 $Curvature factor of combined Fx with load
RHX1 = 0.008847  $Shift factor for combined slip Fx reduction
PTX1 = 1.85      $Relaxation length SigKap0/Fz at Fznom
PTX2 = 0.000109  $Variation of SigKap0/Fz with load
PTX3 = 0.101    $Variation of SigKap0/Fz with exponent of load

[OVERTURNING_COEFFICIENTS]
QSX1 = 0         $Lateral force induced overturning moment
QSX2 = 0         $Camber induced overturning couple
QSX3 = 0         $Fy induced overturning couple

[LATERAL_COEFFICIENTS]
PCY1 = 1.3223    $Shape factor Cfy for lateral forces
PDY1 = 1.0141    $Lateral friction Muy
PDY2 = -0.12274  $Variation of friction Muy with load
PDY3 = -1.0426  $Variation of friction Muy with squared camber
PEY1 = -0.63772  $Lateral curvature Efy at Fznom
PEY2 = -0.050782 $Variation of curvature Efy with load
PEY3 = -0.27333 $Zero order camber dependency of curvature Efy
PEY4 = -8.3143   $Variation of curvature Efy with camber
PKY1 = -19.797   $Maximum value of stiffness Kfy/Fznom
PKY2 = 1.7999    $Load at which Kfy reaches maximum value
PKY3 = 0.0095418 $Variation of Kfy/Fznom with camber
PHY1 = 0.0011453 $Horizontal shift Shy at Fznom
PHY2 = -6.6688e-005 $Variation of shift Shy with load
PHY3 = 0.044112  $Variation of shift Shy with camber
PVY1 = 0.031305  $Vertical shift in Svy/Fz at Fznom
PVY2 = -0.0085749  $Variation of shift Svy/Fz with load
```

```
PVY3 = -0.092912 $Variation of shift Svy/Fz with camber
PVY4 = -0.27907  $Variation of shift Svy/Fz with camber + load
RBY1 = 6.2238    $Slope factor for combined Fy reduction
RBY2 = 3.0734    $Variation of slope Fy reduction with alpha
RBY3 = 0.016076  $Shift term for alpha in slope Fy reduction
RCY1 = 1.0051    $Shape factor for combined Fy reduction
REY1 = 0.019749  $Curvature factor of combined Fy
REY2 = -0.0020691 $Curvature factor of combined Fy with load
RHY1 = -0.0010319 $Shift factor for combined Fy reduction
RHY2 = 7.4123e-006 $Shift factor for combined Fy red. w. load
RVY1 = 0.02962 $Kappa induced side force Svyk/Muy*Fz at Fznom
RVY2 = -0.011053 $Variation of Svyk/Muy*Fz with load
RVY3 = -0.0009317 $Variation of Svyk/Muy*Fz with camber
RVY4 = 11.842    $Variation of Svyk/Muy*Fz with alpha
RVY5 = 1.9       $Variation of Svyk/Muy*Fz with kappa
RVY6 = 0         $Variation of Svyk/Muy*Fz with atan(kappa)
PTY1 = 1.9       $Peak value of relaxation length SigAlp0/R0
PTY2 = 2.25      $Value of Fz/Fznom where SigAlp0 is extreme

[ROLLING_COEFFICIENTS]
QSY1 = 0.01      $Rolling resistance torque coefficient
QSY2 = 0         $Rolling resistance torque depending on Fx
QSY3 = 0         $Rolling resistance torque depending on speed
QSY4 = 0         $Rolling resistance torque depending on speed

[ALIGNING_COEFFICIENTS]
QBZ1 = 7.5088    $Trail slope factor for trail Bpt at Fznom
QBZ2 = -1.9428   $Variation of slope Bpt with load
QBZ3 = 0.61681   $Variation of slope Bpt with load squared
QBZ4 = 0.12231   $Variation of slope Bpt with camber
QBZ5 = 0.50016   $Variation of slope Bpt with absolute camber
QBZ9 = 5.5144    $Slope factor Br of residual torque Mzr
QBZ10 = 0        $Slope factor Br of residual torque Mzr
QCZ1 = 1.2237    $Shape factor Cpt for pneumatic trail
QDZ1 = 0.062582  $Peak trail
QDZ2 = 0.00052585 $Variation of peak Dpt" with load
QDZ3 = -0.60661  $Variation of peak Dpt" with camber
QDZ4 = 8.634     $Variation of peak Dpt" with camber squared
QDZ6 = -0.0048467 $Peak residual torque
QDZ7 = 0.0034983 $Variation of peak factor Dmr" with load
QDZ8 = -0.11032  $Variation of peak factor Dmr" with camber
QDZ9 = 0.021277  $Variation of peak factor Dmr" w. camber+load
QEZ1 = -5.3971   $Trail curvature Ept at Fznom
QEZ2 = 1.1207    $Variation of curvature Ept with load
QEZ3 = 0         $Variation of curvature Ept with load squared
QEZ4 = 0.14942  $Variation of curvature Ept w. sign of Alpha-t
QEZ5 = -1.1429  $Variation of Ept with camber and sign Alpha-t
QHZ1 = -0.00069905 $Trail horizontal shift Sht at Fznom
```

```
QHZ2 = 0.0055192 $Variation of shift Sht with load
QHZ3 = 0.065953  $Variation of shift Sht with camber
QHZ4 = 0.11393   $Variation of shift Sht with camber and load
SSZ1 = 0.022576  $Nominal value of s/R0: effect of Fx on Mz
SSZ2 = 0.024754  $Variation of distance s/R0 with Fy/Fznom
SSZ3 = 0.0014697 $Variation of distance s/R0 with camber
SSZ4 = 0.0014801 $Variation of distance s/R0 with load+camber
QTZ1 = 0.2       $Gyration torque constant
MBELT = 4.9      $Belt mass of the wheel
```

Tire Parameter File - CDTire/Realtime

The following listing shows the input file structure for the tire model *CDTire/Realtime*. For a comprehensive list of the respective parameters of each block, look into the appended table and the example parameter files from the installation.

The unit system is fixed to [N,mm,s,t] (Newton, millimeter second, ton). The parameters are keyword based and reside in respective sections. The 2 mandatory sections are:

- [CDT30-HPS MODEL PARAMETERS]
  contains all geometric, discretization, material and other physical modelling parameters

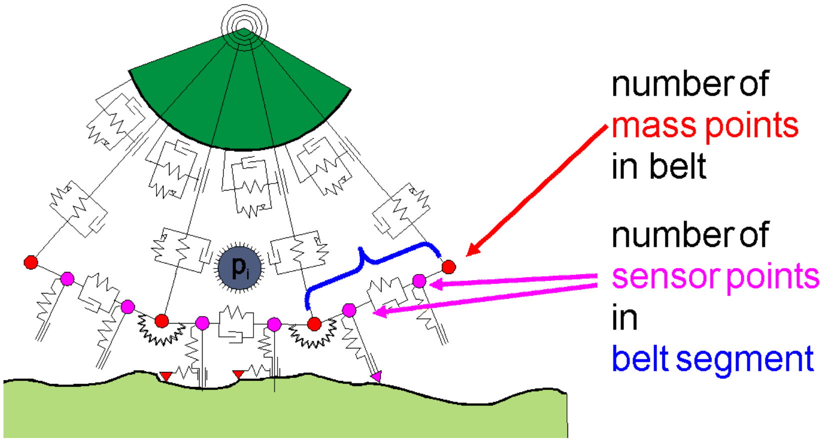
- [CDT30-HPS SOLVER PARAMETERS]
  contains all numerical parameters of the internal integrator

---

Remark: You may edit some parameters to suit your requirements. These parameters are colored blue in the listing above and an according remark is given in the following table. The parameters colored in orange are optional and (if used) change model behavior or introduce new functionality.

All parameters of both sections are explained in the following table.

Name	Explanation	Default	Unit
	[CDT30-HPS MODEL PARAMETERS]		
PIN	Actual inflation pressure (possibly overruled by MBD model	0.25	MPa
PREF	Reference inflation pressure	0.25	MPa
PIN_FLAG	Toggle pressure-dependency of sidewall	0	-
NMP	Number of mass points in belt	100	-
	you may want to edit this value: the distance between two mass points (2 pi RGRT/NMP) must be around half of the fundamental wavelength of the surface, e.g. for a 20x20mm obstacle, this is 20 mm.		

Name	Explanation	Default	Unit
			
R_BELT	Radius of the belt (inflated) (Alternative name: RGRT)	307	mm
R_RIM	Radius of the rim (Alternative name: RFEL)	203	mm
W_BELT	Effective width of the belt (Alternative name: BGRT)	190	mm
MASS_BELT	Mass of belt and tread (Alternative name: MGRT)	5.0E-3	t
MASS_ SIDEWALL	Mass of 1 sidewall (Default is MASS_BELT/4)	0.001	t
MASS_ADD_TO_RIM	(optional) MBD_MASS_ADD_TO_RIM and MBD_MASS_SUB_FROM_WHEEL calculation; does not effect tire simulation	0.001	t
IXX_ADD_TO_RIM	Same for MBD_IXX_xxx calculation	100	t mm^2
IYY_ADD_TO_RIM	Same for MBD_IYY_xxx calculation	200	t mm^2
IZZ_ADD_TO_RIM	Same for MBD_IZZ_xxx calculation	100	t mm^2

Name	Explanation	Default	Unit
FTX	Natural frequency: Translation in x/z direction (mode R_1)	75	Hz
FTY	Natural frequency: Translation in y direction (mode L_0)	38	Hz
FRY	Natural frequency: rotation around y axis (mode C_0)	60	Hz
DTX	Damping coefficient of mode R_1	0.08	-
DTY	Damping coefficient of mode L_0	0.08	-
DRY	Damping coefficient of mode C_0	0.08	-
RAD_NL_MOD	Stiffness influence factor radial (Alternative name: KARED)	0.29	-
CRY_RED_ FLAG	Activates reduction of circumferential rotational sidewall stiffness for large deflections	1	-
CRY_RED_ DEF	Deflection at which reduction of circumferential rotational sidewall stiffness starts	0	mm
CRY_RED_ RES	Residual stiffness factor of circumferential rotational sidewall stiffness at full deflection	1	-
CRX_RED_ FLAG	Activates reduction of lateral rotational sidewall stiffness for large deflections	1	-
CRX_RED_ DEF	Deflection at which reduction of lateral rotational sidewall stiffness starts	0	mm
CRX_RED_ RES	Residual stiffness factor of lateral rotational sidewall stiffness at full deflection	1	-
CIRC_STIFF	Tensile stiffness of belt in circumferential direction (Alternative name: EF)	3.0E+6	N
CIRC_STIFF_COMPRESSION_FACTOR	Optional tensile stiffness factor under compression condition of tensile belt stiffness CIRC_STIFF	0	1
CIRC_DAMP	Damping factor of belt tensile stiffness (Alternative name: D_TAN)	1.0E-5	1/s
RAD_PRE-STRAIN_RED_FACTOR	Optional scaling of inflation pre-strain distribution in radial direction of sidewall model	1	-

Name	Explanation	Default	Unit
Y_BENDING _STIFF	Bending stiffness of the belt (around lateral axis) (Alternative name: EIY)	1.0E+6	Nmm^2
Y_BENDING _DAMP	Damping factor of belt bending stiffness (Alternative name: D_ALPHA)	1.0E-5	1/s
TREAD_NSEN_X	Number of circumferential sensor points in belt segment (Optional: NSEN)	5	-
TREAD_HEIGHT	Height of tread (Alternative name: HL)	10	mm
TREAD_EG	Young's modulus of the tread rubber times tread width per circumferential unit length (Alternative name: EG)	120	N/mm^2
TREAD_GG	Simultaneous setting of TREAD_GG_X and TREAD_GG_Y (Alternative name: BL)	40.0	N/mm^2
TREAD_GG_X	Shear modulus of the tread rubber times tread width per circumferential unit length in circumferential direction	40.0	N/mm^2
TREAD_GG_Y	Shear modulus of the tread rubber times tread width per circumferential unit length in lateral direction	40.0	N/mm^2
TREAD_RAD_D	Damping factor of radial tread stiffness (Alternative name: D_RAD_TREAD)	5.0E-4	1/s
TREAD_KM	Shear stiffness reduction coefficient (Alternative name: KM)	0.9	1
TREAD_SCAN _HEIGHT	Height in mm above surface where contact sensors are active	150.0	mm
TREAD_MAX _COMPRESS	Maximum compression of tread before warning is issued (and capped)	0.95	-
KSRED	Stiffness influence factor lateral	-70	-
PNEUMATIC _TRAIL_SCALE	Optional scaling of the pneumatic trail	1.0	-
KSRED _ADVANCED	Optional lookup table for scaling of KSRED as function of preload via $[F_0,S_0,\ldots,F_N,S_N]$ with linear interpolation and constant extrapolation	[-100,1]	[N,-,…]
PNEUMATIC _TRAIL_SCALE _ADVANCED	Optional lookup table for scaling of PNEUMATIC_TRAIL_SCALE as function of preload via $[F_0,S_0,\ldots,F_N,S_N]$ with linear interpolation and constant extrapolation	[-100,1]	[N,-,…]

Name	Explanation	Default	Unit
MU	Relative friction coefficient (e.g. [1.2, 1.2, 1.0], alternative name: MGLT)	table	-
V_MU	Sliding velocity (e.g. [0.0, 1000, 10000], alternative name: VGLT)	table	mm/s
MU_GLOBAL _SCALEFACTOR	Global scaling factor of friction	1	-
MU_PRELOAD _DEPENDENCY	Optional preload dependent scaling of friction M from [F_{REF}, S, M_{MIN}, M_{MAX}] via $M = 1 – S * (F / F_{REF} - 1)$	[3000,0.2, 0.7,1.3]	[N,-,-,-]
LDE_FLAG	Activates LDE (Large Deformation Element) calculation for tire ground out (bottoming)	0	-
LDE_CNL	Radial stiffness of non-linear part per circumferential unit length	30	N/mm^2
LDE_CLIN	Radial stiffness of linear part per circumferential unit length	150	N/mm^2
LDE_RNL	Radius from rim at which non-linear part becomes active (must be > LDE_RLIN)	20	mm
LDE_RLIN	Radius from rim at which linear part becomes active	10	mm
R_STAT	Unloaded effective radius	317	mm
R_STAT	Unloaded static radius	317	mm
CR1_STAT	Linear static vertical stiffness	250	N/mm
ADVANCED	Optional scaling of sidewall shear damping as function of rotational velocity via $[\omega_0,s_0,\omega_1,s_1]$, linear interpolation and constant extrapolation	[20,3,40,1]	[rad/s, -, rad/s, -]
CORRECT _WEIGHT_TO _NOMINAL _FLAG	Mimic nominal tire weight	0	-
	[CDT30-HPS SOLVER PARAMETERS]		
TOL	Error tolerance of internal integrator	1.0E-4	-
DTM	Maximum step size of internal integrator	2.0E-4	s
DTMIN	Minimum step size of internal integrator	1.0E-10	s
DT_START _EXPL	Initial step size of internal explicit integrator	2.0E-4	s

Name	Explanation	Default	Unit
TYPE	Explicit 1, Implicit 2	1	-
UPDATE_FOR_MASTERCORRECTOR	Toggle corrector or Newton iterations to be taken into account (0 off, 1 on)	0	-
PRE_STEP_TIME	Duration of inflation pre-step before beginning of simulation	0.05	s
PRE_STEP_DEFLTIME	Duration of deflection pre-step before beginning of simulation (adjusted automatically)	0.2	s
PRE_STEP_SAFETY_MARGIN	Height above ideal contact point for initial inflation phase	10	mm
PRE_STEP_LDE_MARGIN	Minimal clearance (from rim point) for legal initial deflection	10	mm
FORCE_NOSUCCESS	Returned force value in case of no convergence	1.0e+10	N
ALPHA_EXPLICIT	Explicit Newmark alpha integrator value	0	-
BETA_EXPLICIT	Explicit Newmark beta integrator value	0.166667	-
GAMMA_EXPLICIT	Explicit Newmark gamma integrator value	0.5	-
ALPHA_IMPLICIT	Implicit Newmark alpha integrator value	0	-
BETA_IMPLICIT	Implicit Newmark beta integrator value	0.25	-
GAMMA_IMPLICIT	Implicit Newmark gamma integrator value	0.5	-
NMAX_IMPL_ITER	Maximum number of iteration for the implicit integrator	3	-
IMPL_STEP_CTRL_ENABLE	Toggle internal step size control of implicit integrator (0 off, 1 on)	1	-
IMPL_STEP_CTRL_EPS	Percentage of error tolerance TOL used to activate step size control	200	-
IMPL_STEP_CTRL_NSUBSTEPS	Subdivision of steps if step size reduction is activated for implicit integrator	3	-

Name	Explanation	Default	Unit
IMPL_JAC_EVAL_AT_ITER	Toggle update of jacobian calculation during iteration (0 off, 1 on) for implicit integrator	0	-

Tire Parameter File for CDTire/3D

The following listing shows the input file structure of the tire model *CDTire/3D*. For a comprehensive list of the respective parameters of each block, look into the appended table and the example parameter files from the installation.

The unit system is fixed to [N,mm,s,t] (Newton, millimeter second, ton). The parameters are keyword based and reside in respective sections. The 2 mandatory sections are:

- [CDT50-N MODEL PARAMETERS]
  contains all geometric, discretization, material and other physical modelling parameters (except SW_MODE=40 parameters)
- [CDT50-N SOLVER PARAMETERS]
  contains all numerical parameters of the internal integrator

and 4 optional section:

- [CAVITY MODEL PARAMETERS]
  contains al CAVITY_MODEL_FLAG = 1 parameters for compressible Euler flow model

- [CDT40-N MODEL PARAMETERS]
  contains all SW_MODE = 40 parameters for analytical sidewall model
- [TIRE_AND_RIM_RESIZING]
  contains reference and target tire and rim specification for automatic resizing
- [CDT50-N ADVANCED OUTPUT PARAMETERS]
  contains advanced output options for post processing via CDTireViewer

The parameters may contain one- or two-dimensional arrays. One has to be careful about the lengths of these arrays. There are 3 types of entities utilizing arrays:

- ring entities (table length is NR)
- segment entities (table length is NR-1)
- contact entities

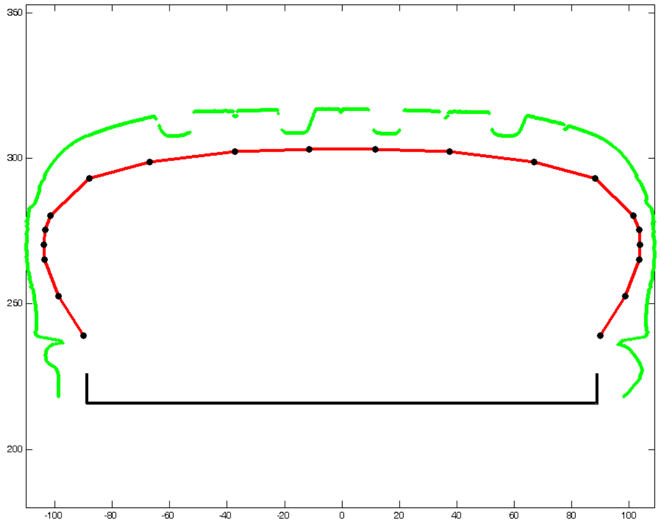
Contact entities can have 2 sizes: Associated mass points (table length NR-2*(NRSENSTART-1) with linear interpolation for the sensors) or directly number of sensors (table length (NR-2*(NRSENSTART-1)-1)*TREAD_NSEN_Y). If NRSENSTART is not set, it defaults to NRSW+1.

Ring entities are all entities that are associated with mass, geometry or circumferential properties, e.g. MASS_W, CONTOUR_SHELL_Y or RUBBER_CIRC_EH_W. Segment entities are all entities associated with lateral or diagonal properties, e.g. RUBBER_LAT_EH_W or RUBBER_DIAG_EH_W.

Additionally, many entities consist of a material property and an associated weight, e.g. X_BENDING_STIFF and X_BENDING_STIFF_W. The local property then is a multiplication of the material property with its associated weight. In that way, it is possible to easily modify one local property or all properties simultaneously.

Remark: You may edit some parameters to suit your requirements. These parameters are colored blue in the listing below and an according remark is given in the following table. The parameters colored in orange are optional and (if used) change model behavior or introduce new functionality.

Name	Explanation	Default	Unit
	[CDT50-N MODEL PARAMETERS]		
PIN	Actual inflation pressure (maybe overruled by interface mechanism)	0.25	MPa
NCS	Number of cross sections	50	-
NR	Number of rings	14	-
NRSW	Number of rings in either sidewall (including bead node)	4	-

Name	**Explanation**	**Default**	**Unit**
NRSENSTART	Index of ring from where contact calculation starts	NRSW+1	-
SW_MODE	Materialized sidewall (50) or analytical sidewall (40)	50	-
CONTOUR_SHELL_Y	Lateral cross section coordinate of reference configuration, ring entity	Table	mm
CONTOUR_SHELL_Z	Radial cross section coordinate of reference configuration, ring entity  	Table	mm
MASS_SIDEWALL	Mass of one sidewall (including bead)	0.003	t
MASS_BELT	Mass of belt	0.006	t
MASS_BEAD	Mass of one bead	0.001	t
MASS_W	Weighting factors of mass distribution (table of length NR), ring entity	table	-
MASS_ADD_TO_RIM	Used for MBD_MASS_ADD_TO_RIM and MBD_MASS_SUB_FROM_WHEEL calculation; does not affect tire simulation	0.001	t
IXX_ADD_TO_RIM	Same for MBD_IXX_xxx calculation	100	t mm^2
IYY_ADD_TO_RIM	Same for MBD_IYY_xxx calculation	200	t mm^2
IZZ_ADD_TO_RIM	Same for MBD_IZZ_xxx calculation	100	t mm^2
RUBBER_CIRC_EH	Rubber stiffness in circumferential direction (think Young E * thickness H)	40	N/mm
RUBBER_LAT_EH	Rubber stiffness in lateral direction (think Young E * thickness H)	40	N/mm
RUBBER_DIAG_EH	Rubber stiffness in diagonal direction (think Young E * thickness H)	10	N/mm

Name	Explanation	Default	Unit
RUBBER_SHEAR_GH	Remaining rubber shear stiffness (think shear modulus G * thickness H)	10	N/mm
RUBBER_XXX_DAMP	Corresponding (CIRC, LAT,DIAG, SHEAR) damping factors	0.0003	1/s
RUBBER_XXX_EH_W	Corresponding (CIRC, LAT,DIAG, SHEAR) weighting factors, ring or segment entity	table	-
CARCASS_CORDLAYER _STIFF	Carcass stiffness in cord angle direction (think Young E * thickness H)	400	N/mm
CARCASS_CORDLAYER _DAMP	Carcass damping factor in cord angle direction	5.0E-6	1/s
CARCASS_CORDLAYER _STIFF_W	Carcass stiffness weighting factors, segment entity	Table	-
CARCASS_CORDLAYER _L0_REDFACTOR	Carcass zero length factor relative to reference configuration, segment entity	Table	-
BANDAGE_CORDLAYER _STIFF	Bandage stiffness in cord angle direction (think Young E * thickness H)	1500	N/mm
BANDAGE_CORDLAYER _DAMP	Bandage damping factor in cord angle direction	5.0E-6	1/s
BANDAGE_CORDLAYER _STIFF_W	Bandage stiffness weight factors, ring entity	Table	-
BANDAGE_CORDLAYER _L0_REDFACTOR	Bandage zero length factor relative to reference configuration, ring entity	Table	-
NUMB_CARCASS_ CROSSPLY_ CORDLAYERS	Number of carcass cross ply layers, optional	0	-
CARCASS_ CROSSPLY_ CORDLAYERS_STIFF_ COMPRESSION_ FACTOR	Cordlayer stiffness factor under compression condition, direct multiplication.	0.2	-
CARCASS_ CROSSPLY_ CORDLAYERS_ANGLE __1	Carcass cord angle from circumferential direction for cross ply layer. Must be given explicitly for each layer __1 to __N	88	deg
CARCASS_ CROSSPLY_ CORDLAYERS_STIFF __1	Cordlayer stiffness in cord angle direction (think Young E * thickness H). Must be given explicitly for each layer __1 to __N	500	N/mm
CARCASS_ CROSSPLY_ CORDLAYERS_DAMP __1	Cordlayer damping factor in cord angle direction. Must be given explicitly for each layer __1 to __N	5.0E-6	1/s

Name	Explanation	Default	Unit
CARCASS_ CROSSPLY_ CORDLAYERS_STIFF_ W__1	Local cordlayer stiffness factor in cord angle direction (think Young E * thickness H). Must be given explicitly for each layer __1 to __N	[1,..,1]	-
CARCASS_ CROSSPLY_ CORDLAYERS_L0_ REDFACTOR__1	Local cordlayer zero length factor relative to reference configuration. Must be given explicitly for each layer __1 to __N	[1,..,1]	-
NUMB_STEEL _CORDLAYERS	Number of steel cord layers	2	-
STEEL_CORDLAYER _ANGLE	Angle of steel cord layers against circumferential direction	[26,-26]	deg
STEEL_CORDLAYER _STIFF	Cordlayer stiffness in cord angle direction (think Young E * thickness H)	[3000,3000]	N/mm
STEEL_CORDLAYER _DAMP	Cordlayer damping factor in cord angle direction	[5e-6,5e-6]	1/s
STEEL_CORDLAYER _STIFF_COMPRESSION _FACTOR	Cordlayer stiffness factor under compression condition, direct multiplication	0.2	-
STEEL_CORDLAYER _L0_REDFACTOR	Cordlayer zero length factor relative to reference configuration	[0.998, 0.998]	-
NUMB_DISCRETE _STRIPES_IN_STEEL _CORDLAYER	Number of discrete stripes in steel cord layer	2	-
X_BENDING_STIFF	Bending stiffness in lateral direction (think Young E * thickness H^3/12)	12000	Nmm
X_BENDING_DAMP	Bending damping factor in lateral direction	0.0005	1/s
X_BENDING_STIFF_W	Bending stiffness weighting factors in lateral direction, ring entity	table	-
X_BENDING_ALPHANL	Angle where non-linear progression starts (it ends at angle 0)	0	rad
X_BENDING_EXPNL	Exponent of non-linear progression (c * (x-x0)^Y_BENDING_EXPNL))	1	-
X_BENDING_PREANGLE	Local zero angle relative to reference configuration	[0,0,.., 0,0]	rad
X_BENDING_STIFF _UNILAT_ADDFACTOR	Additional local stiffness factor	[0,0,.., 0,0]	-
Y_BENDING_STIFF	Bending stiffness in circumferential direction (think Young E * thickness H^3/12)	8000	Nmm
Y_BENDING_DAMP	Bending damping factor in circumferential direction	0.0005	1/s

Name	Explanation	Default	Unit
Y_BENDING_STIFF_W	Bending stiffness weighting factors in circumferential direction, segment entity	table	-
Y_BENDING_ALPHANL	Angle where non-linear progression starts (it ends at angle 0)	0	rad
Y_BENDING_EXPNL	Exponent of non-linear progression (c * (x-x0)^Y_BENDING_EXPNL))	1	-
XY_DIAG_BENDING _STIFF	Bending stiffness in diagonal direction (think Young E * thickness H^3/12)	10000	Nmm
XY_DIAG_BENDING _DAMP	Bending damping factor in diagonal direction	0.0005	1/s
XY_DIAG_BENDING _STIFF_W	Bending stiffness weighting factors in diagonal direction, segment entity	table	-
XY_BENDING_ ALPHANL	Angle where non-linear progression starts (it ends at angle 0)	0	rad
XY_BENDING_ EXPNL	Exponent of non-linear progression (c * (x-x0)^Y_BENDING_EXPNL))	1	-
TREAD_NSEN_X	Number of sensors per element in circumferential direction	7	-
TREAD_NSEN_Y	Number of sensors per element in lateral direction	5	-
TREAD_HEIGHT	Height of tread sensors	table	mm
TREAD_SCAN_HEIGHT	Height above ideal contact point on surface within where contact sensors are active	200	mm
TREAD_RAD_NL_TYPE	Type of progression of radial tread stiffness (0..linear, 1..Neo-Hooke-like)	1	-
TREAD_MAX_COMPRESS	Maximum relative compression of tread (capped and warning is issued)	0.95	-
TREAD_RAD_D	Radial tread damping factor	0.0001	1/s
TREAD_RAD_D _DEGRESSION_FACTOR	Radial tread damping residual factor (active above digression velocity)	1	-
TREAD_RAD_D _DEGRESSION_VEL	Radial tread damping digression velocity	0	mm/s
TREAD_E/H	Radial tread stiffness (think Young E / thickness H)	0.3	N/mm^3
TREAD_Gx/H	Tread shear stiffness in circumferential direction (think shear G / thickness H)	0.1	N/mm^3
TREAD_Gy/H	Tread shear stiffness in lateral direction (think shear G / thickness H)	0.1	N/mm^3

Name	Explanation	Default	Unit
TREAD_RUBBER_W	Local tread rubber stiffness modification, direct multiplication, optional	[1,..,1]	-
TREAD_HEIGHT_REF	Optional scaling of tread stiffness properties with H_{REF} / H_i	H_{MAX}	mm
MU	Relative friction coefficient e.g. [1.2, 1.2, 1.0]	table	-
V_MU	Sliding velocity e.g. [0.0, 1000, 10000]	table	mm/s
MU_GLOBAL _SCALEFACTOR	Optional global scaling factor of friction	1	-
MU_LOCAL_W	Optional local scaling of friction (to adapt for different tread rubber material)	table	-
MU_NSTRESS _DEPENDENCY	Optional normal stress dependent scaling of friction M from [n_{REF}, S, M_{MIN}, M_{MAX}] via $M = 1 – S * (n / n_{REF} - 1)$	[0.35,0.3, 0.7,1.3]	[MPa,-,-,-]
LOSSENERGY_FLAG	Toggle energy loss post-processing	0	-
THERMAL_MODEL_FLAG	Toggle CDTire/Thermal usage	0	-
CAVITY_MODEL_FLAG	Select cavity simulation model	0	-
ADVANCED	Scale rubber shear damping as function of rotational velocity via [ω_0,s_0,ω_1,s_1], linear interpolation and constant extrapolation	[20,3,40,1]	[rad/s, -, rad/s, -]
CORRECT_WEIGHT _TO_NOMINAL_FLAG	Flag to mimic nominal tire weight	0	-
MASS_UPDATE _NOCAVITY	Add mass to belt to adjust part of missing cavity gas mass	0	t
LDE_FLAG	Toggle Large Deformation Element	0	-
LDE_Y_COORD	Lateral coordinate of LDE weighting	table	mm
LDE_W	LDE weighting spline	table	-
LDE_CNL	Radial LDE progression stiffness	1.0E-9	N/mm^2
LDE_CLIN	Radial LDE final stiffness	0	N/mm^2
LDE_RNL	Radial LDE progression radius	1.0E-9	mm
LDE_RLIN	Radial LDE final radius	0	mm
LDE_SCAN_RADIUS	Enable LDE search (from rim point)	20	mm
LDE_ACTIVE_RADIUS	Signal LDE is active (from rim point)	10	mm

Name	Explanation	Default	Unit
R_EFF	Unloaded effective radius	320	mm
R_STAT	Unloaded static radius	320	mm
CR1_STAT	Static linear radial stiffness	250	N/mm
	[CAVITY MODEL PARAMETERS]		
RADIUS_EFFECTIVE	Radius of gas column	260	mm
SOUND_VELOCITY	Velocity of sound	340000	mm/s
CFL_FACTOR	Courant number from Courant-Fiedrichs-Lewy condition	0.3	-
DX_RESAMPLE_FACTOR	Number of cavity dof’s per segment	5	-
A_RIM	Cross section area of rim cavity not covered by tire nodes	0	mm^2
	[CDT40-N SOLVER PARAMETERS]		
PREF	Reference inflation pressure	0.25	MPa
PIN_FLAG	Toggle pressure-dependency of sidewall	0	-
MASS_ADD_TO_BELT	(optional) parameter to accommodate the massless sidewall modeling	0.001	t
MASS_ADD_TO_RIM	Used for MBD_MASS_ADD_TO_RIM and MBD_MASS_SUB_FROM_WHEEL calculation; does not effect tire simulation	0.001	t
IXX_ADD_TO_RIM	Same for MBD_IXX_xxx calculation	100	t mm^2
IYY_ADD_TO_RIM	Same for MBD_IYY_xxx calculation	200	t mm^2
IZZ_ADD_TO_RIM	Same for MBD_IZZ_xxx calculation	100	t mm^2
BEAD_OFFSET_Y	Lateral bead offset compensation	0	mm
BEAD_OFFSET_Z	Radial bead offset compensation	20	mm

Name	Explanation	Default	Unit
INPUT_MODE	Optionally switches sidewall model (0,1,2,3)	0	-
FTX	Natural frequency: Translation in x/z direction (mode R_1)	89.5	Hz
FTY	Natural frequency: Translation in y direction (mode L_0)	45.7	Hz
FRY	Natural frequency: rotation around y axis (mode C_0)	65.4	Hz
DTX	Damping coefficient (mode R_1)	0.05	-
DTY	Damping coefficient (mode L_0)	0.05	-
DRY	Damping coefficient (mode C_0)	0.05	-
SW_ANGLE	Reference sidewall angle for INPUT_MODE=1,2,3	28	Deg
CRX	Lateral rotational foundational sidewall stiffness for INPUT_MODE=2	5.5e6	Nmm
CRY	Circumferential rotational foundational sidewall stiffness for INPUT_MODE=2	7.0e6	Nmm
CRX_S	Lateral rotational structural sidewall stiffness for INPUT_MODE=3	3.2e6	Nmm
CRY_S	Circumferential rotational structural sidewall stiffness for INPUT_MODE=3	4.5e6	Nmm
SWBEND	Percent radial stiffness due to bending	20	-
CRY_RED_DEF	Deflection value at which reduction of circumferential rotational sidewall stiffness starts	0	mm
CRY_RED_RES	Residual stiffness factor of circumferential rotational sidewall stiffness at full deflection	1	-
CRX_RED_DEF	Deflection value at which reduction of lateral rotational sidewall stiffness starts	0	mm
CRX_RED_RES	Residual stiffness factor of lateral rotational sidewall stiffness CRY at full deflection	1	-

Name	Explanation	Default	Unit
	[CDT50-N SOLVER PARAMETERS]		
TOL	Error tolerance of internal integrator	1.0E-4	-
TOL_EXCEPTION	Error tolerance of internal integrator in case of failed convergence	0.01	-
DTM	Maximum step size of internal integrator	5.0E-5	s
DTMIN	Minimum step size of internal integrator	1.0E-10	s
DT_START_EXPL	Initial step size of internal explicit integrator	5.0E-5	s
PRE_STEP_TIME	Duration of inflation pre-step before beginning of simulation	0.05	s
PRE_STEP_DEFLTIME	Duration of deflection pre-step before beginning of simulation (adjusted automatically)	0.2	s
PRE_STEP_SAFETY _MARGIN	Height above ideal contact point for initial inflation phase	10	mm
PRE_STEP_LDE_MARGIN	Minimal clearance (from rim point) for legal initial deflection	10	mm
FORCE_NOSUCCESS	Returned force value in case of no convergence	1.0e+10	N
TYPE	Explicit 1	1	-
ALPHA _EXPLICIT	Explicit Newmark alpha integrator value	0	-
BETA _EXPLICIT	Explicit Newmark beta integrator value	0.166667	-
GAMMA _EXPLICIT	Explicit Newmark gamma integrator value	0.5	-
UPDATE_FOR _MASTERCORRECTOR	Toggle corrector iterations to be taken into account (0 off, 1 on)	0	-

Name	Explanation	Default	Unit
	[TIRE_AND_RIM_RESIZING]		
TIRE_REF	Reference tire specification	205/50R16	-
RIM_REF	Reference rim specification	16x6	-
TIRE_NEW	Target tire specification	225/45R17	-
RIM_NEW	Target rim specification	17x7	-
	[CDT50-N ADVANCED OUTPUT PARAMETERS]		
T_START	Start of output simulation time	0	s
T_END	End of output simulation time	100	s
DT_OUT	Output step size	0.01	s
OUTPUT_TIRESTATES	Flag to output the tire states (0 = off, 1 = on)	0	-
OUTPUT_ ROADCONTACTFORCES	Flag to output the road contact forces (0 = off, 1 = on)	0	-
TAKE_LOGFILE-NAME_AS_PREFIX	Naming convention of resulting output file	-	-

Road Parameters

The following paragraphs show detailed examples for

- equidistant track data and
- non-equidistant track data.

Each example contains a road definition file and a figure displaying the defined road surface.

Example for Equidistant Track Data (Data Type 2)

```
# EXAMPLE EQUIDISTANT TRACK DATA
# X0_ROAD   Y0_ROAD   Z0_ROAD   MU_ROAD
  200.0     200.0     50.0      1.0
# DATA TYPE : EQUIDISTANT TRACK DATA
  2
# NTRACKS
  2
# NDATA  X0_TRACK  Y0_TRACK  HALF_WIDTH  DX    MU_TRACK
  21     -300      -150      150         25    1.0
    0.0000
   -9.5492
  -34.5492
  -65.4508
  -90.4508
 -100.0000
  -90.4508
  -65.4508
  -34.5492
   -9.5492
    0.0000
   -9.5492
  -34.5492
  -65.4508
  -90.4508
 -100.0000
  -90.4508
  -65.4508
  -34.5492
   -9.5492
    0.0000
# NDATA  X0_TRACK  Y0_TRACK  HALF_WIDTH  DX    MU_TRACK
  4      -100      350       150         200   1.0
    50.0000
   100.0000
```

```
   100.0000
    50.0000
END
```

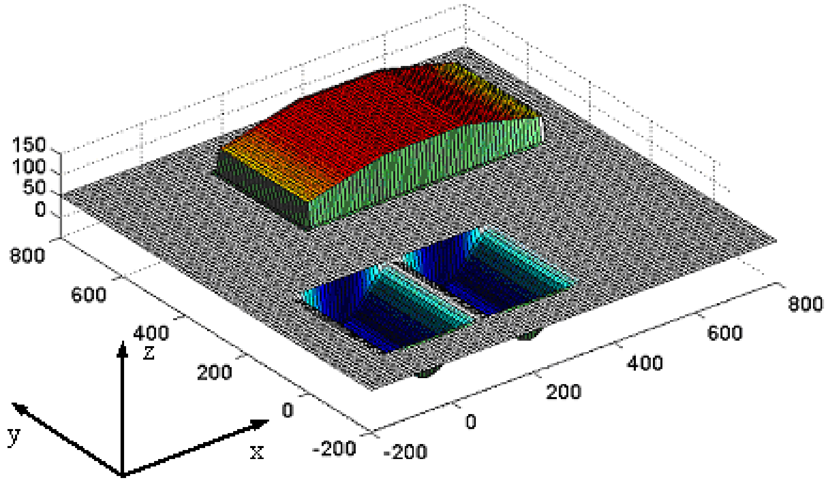


Fig. 7: Road Surface Model 1000: equidistant track

Example for Non-Equidistant Track Data (Data Type 3)

```
# EXAMPLE NON-EQUIDISTANT TRACK DATA
# X0_ROAD   Y0_ROAD   Z0_ROAD   MU_ROAD
  200.0     200.0     50.0      1.0
# DATA TYPE : NON-EQUIDISTANT TRACK DATA
  3
# NTRACKS
  1
# NDATA  X0_TRACK  Y0_TRACK  HALF_WIDTH   MU_TRACK
  24     -300       100       400     1.0
     0.0000    0.0000
    25.0000   -9.5492
    50.0000  -34.5492
    75.0000  -65.4508
   100.0000  -90.4508
   125.0000 -100.0000
   225.0000 -100.0000
   250.0000  -90.4508
   275.0000  -65.4508
   300.0000  -34.5492
   325.0000   -9.5492
   350.0000    0.0000
   450.0000    0.0000
```

```
    475.0000    9.5492
    500.0000   34.5492
    525.0000   65.4508
    550.0000   90.4508
    575.0000  100.0000
    675.0000  100.0000
    700.0000   90.4508
    725.0000   65.4508
    750.0000   34.5492
    775.0000    9.5492
    800.0000    0.0000
END
```

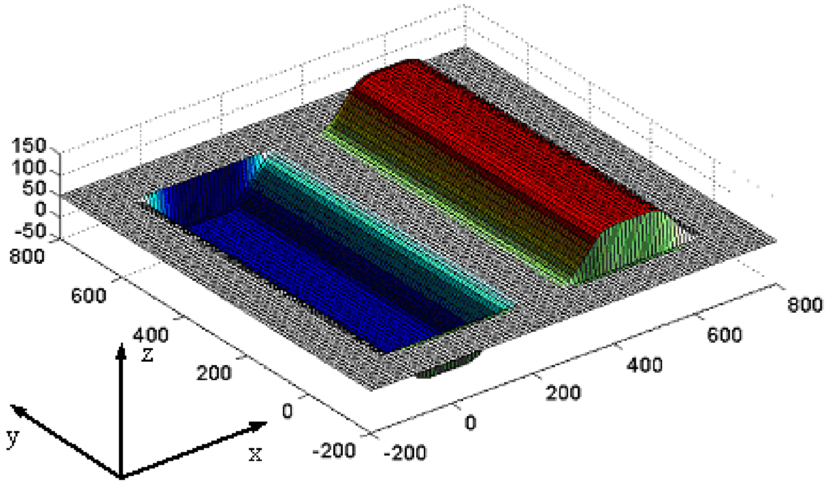


Fig. 8: Road Surface Model 1000: non-equidistant track

Warnings and Errors

For errors and warnings, please see the CDTire log files and/or the log files of the respective MBS solver run.