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Subject	Release-notes for CONTACT version 13.1

These release-notes document the changes in CONTACT version 13.1 with respect to the previous version 12.2. The main change concerns the solution of conformal contact problems. Besides that, we present further speed-up of the normal contact solver and further improvements with respect to presentation of the results.

1 Solving conformal contact problems

A main hypothesis underlying Kalker's original contact model is that the contact area is small compared to the dimensions of the contacting bodies as a whole:

- "The contact lies approximately in a plane, with constant normal direction throughout the contact area."
- "The elastic deformation under stress can be approximated well by that of the elastic half-space, which are known analytically."

These assumptions are also at the basis of many theoretical developments, e.g. Hertz, Carter, Johnson. However, their validity is questionable for contact between the wheel flange root and rail gauge corner. The radius of curvature may go down to $10\,mm$ or less, see Figure 2, and the normal direction may change by $40°$ within a distance of only $7\,mm$.

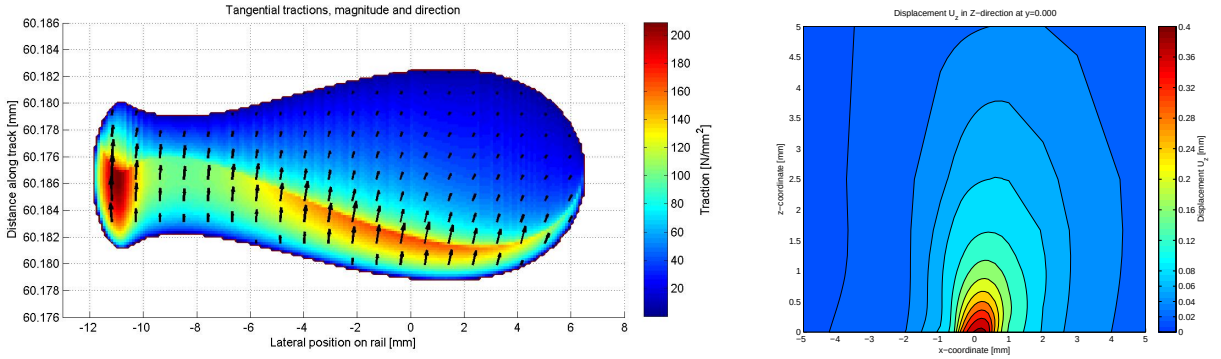

Figure 1: *Left: new type of plot for tangential tractions, showing magnitude and direction in one plot. Right: new plot of subsurface stress, using logarithmic color-scale.*

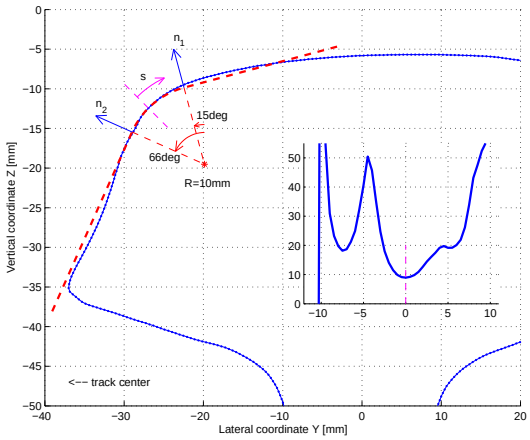

Figure 2: *Measured worn rail profile. At the gauge corner the surface normal changes direction by* 41° *in a distance of only* 7 *mm, such that the half-space approach is not valid anymore.*

We presented our approach for taking the effects of conformality into account at the recent IAVSD conference [1]. One main aspect is to replace the half-space by the so-called "quasi quarter-space": a wedge shape with rounded corner, indicated by the red dashed line in Figure 2. The elastic response of this quasi quarter-space is computed numerically using the finite element method, and provided to CONTACT via a file of "numerical influence coefficients". The relevance of these extensions is indicated by the results of Table 1, showing marked effects of conformal contact modeling.

This option is activated by selecting `C` = 3. An additional line of input is then required:

`CFNAME`	[–]	Filename for the input-file with numerically computed influence coefficients.

Numerically calculated influence coefficients can be combined with material models `M` = 0 and 4. On the one hand, these material models will be used as "best guess" when subsurface stresses are requested. On the other hand this allows for using the interfacial layer model in conformal contact situations too.

2 Further speed-up for rough contacts

A further speed-up of solving the normal contact problem has been realised. This is particularly interesting for rough contact problems where a great level of detail is required (Figure 3). The algorithm for determining the appropriate shape of the contact area is now fully integrated into the Conjugate Gradient (CG) solver. A preconditioner for CG has been developed on the basis of the Fast Fourier Transform (FFT). Last but not least, an elegant way has been found for imposing a prescribed total force in CG as well. These developments will be presented in two scientific papers shortly, and are already incorporated in this release.

	Semi-axes a, b	Contact area	Total force F_n	Max.pressure
Test 1: $R_{yw} = -10.5\,mm, F_n = 20\,kN$				
- Hertzian/planar contact	$4.0, 4.0\,mm$	$47.4\,mm^2$	$20.0\,kN$	$637\,N/mm^2$
- Conformal contact	$4.2, 2.6\,mm$	$34.1\,mm^2$	$17.3\,kN$	$795\,N/mm^2$
Test 2: $R_{yw} = -13.0\,mm, F_n = 20\,kN$				
- Hertzian/planar contact	$4.8, 1.6\,mm$	$26.2\,mm^2$	$20.0\,kN$	$1153\,N/mm^2$
- Conformal contact	$5.2, 1.1\,mm$	$18.4\,mm^2$	$18.0\,kN$	$1520\,N/mm^2$
Test 3: $R_{yw} = -10.5\,mm, F_n = 100\,kN$				
- Hertzian/planar contact	$6.8, 6.0\,mm$	$139.\,mm^2$	$100.\,kN$	$1091\,N/mm^2$
- Conformal contact	$7.4, 4.1\,mm$	$94.0\,mm^2$	$86.7\,kN$	$1397\,N/mm^2$
Test 4: $R_{yw} = -13.0\,mm, F_n = 100\,kN$				
- Hertzian/planar contact	$8.4, 2.8\,mm$	$77.4\,mm^2$	$100.\,kN$	$1980\,N/mm^2$
- Conformal contact	$9.0, 1.9\,mm$	$53.6\,mm^2$	$90.8\,kN$	$2606\,N/mm^2$

Table 1: *Comparison of Hertzian/planar with conformal contact calculations for four scenarios with different vehicle load and conformality [1].*

3 Presentation of the results

Several smaller extensions are made to the Matlab plotting routines for inspecting results:

- A new type of plot `'ptabs+vec'` is introduced that shows the magnitude of the stresses along with their direction, see Figure 1, left. By introducing options `x_offset` and `y_offset`, the results can be put at the actual position on the rail.
- A new option is introduced for inspecting the subsurface stresses as well, see Figure 1, right. This uses a logarithmic color-scale.
- The full details of the subsurface stress tensor are made available via the option `A` = 3.
- The display of the contact area in the `.out`-file is clipped, zooming in on the actual contact area.

4 Resolved problems

No serious bugs were found in CONTACT in the past period. A few smaller problems that are resolved are as follows:

- Write-protected output-files are now detected and handled appropriately.
- A slight memory-leak has been fixed that occurred in runs with many consecutive cases.
- The CONTACT GUI, which is programmed in Java, is adapted for functioning with Java version 1.7.

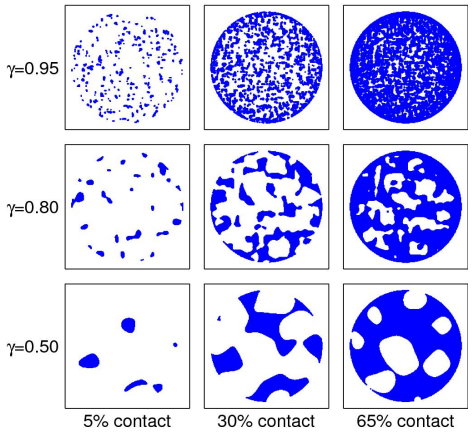

Figure 3: *Illustration of contact patches for a rigid punch pressed onto a rough surface. Left to right: increasing approach δ_z. Bottom to top: increasing roughness, γ.*

5 Compatibility w.r.t. previous versions

In order to change from the previous to the current release, a single change may have to be made to the user's input files.

- Input-option `E` = 2 for the element-wise specification of the rigid slip is changed into `E` = 9.

There have been minor changes to the output-files as well.

- The picture of the contact area is clipped, zoomed in on the actual contact area, and shows better indication of the element numbers involved.
- The Newton-Raphson process for adapting penetration to a prescribed total normal load disappeared because of the new solver that is used.
- The sensitivity `DFN/DPEN` is no longer computed, a zero is displayed in the output-file.

6 Known problems and restrictions

The Windows uninstaller does not support multiple versions (v12.1, v13.1) side by side. If you want to uninstall a previous version then do it first, before installing a newer version. If an installation is broken, consult the "Installation" section in the file `README.txt` for manual installation tips.

One feature that is not treated well is the rolling direction parameter `CHI`. It is generally advised to use `CHI` = 0° or restrict `CHI` to at most a few degrees.

The results may contain a significant discretisation error when a small number of elements (7×7, 15×15) is used. Particularly the frictional work appears to be susceptible to this.

Premium version

There are two versions of CONTACT: a free version and a premium version. These are both comprised in the same code. The premium version contains all basic functionality plus several extended features: fast calculation, conformal contact, third body layer, extended support, etc. These features are marked blue in these release notes and in the User guide. Licenses are provided for this functionality, see `www.kalkersoftware.org/index.php?cid=premium`.

Further information

For more information concerning the program (questions, remarks, suggestions), publications, possible trainings and materials, information w.r.t. licences, consultancy, research proposals, etc, you may contact us at `feedback@kalkersoftware.org`.

References

[1] E.A.H. Vollebregt and A. Segal. Solving conformal contact problems. In W. Zhang, editor, *Proceedings of the 23rd International Symposium on Dynamics of Vehicles on Roads and Tracks*, Qingdao, P.R. China, 2013. IAVSD.