

Contact of Rough Spheres: Greenwood-Tripp model

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Model description

To make a truly predictive model linking contact area and force in contact of rough spheres, Greenwood and Tripp constructed a model taking into account averaged deformations induced by the contact pressure due to asperity contact [1]. This model, initially constructed for spherical contact, could be extended to arbitrary contact shape (its implementation for the axisymmetric contact is provided in github.com/vyastreb/Greenwood-Tripp-Model

The main feature of the model is that it solves the problem in an iterative way by computing pressures from the separation field using multi-asperity model, then it computes induced displacements using integral convolution, recomputing separations and so on before the convergence. The pressure $p^i(x, y)$ induced by asperity contact based on a statistical multi-asperity model for the separation $z_0^i(x, y)$ between two surfaces is given by the following equation

$$p^i(x, y) = \frac{4}{3} \eta E^* r^{1/2} \int_{z_0^i(x, y)}^{\infty} (z - z_0^i(x, y))^{3/2} P(z) dz, \quad (1)$$

where η is the asperity density (m^{-2}), r (m) their average geometrically mean curvature radius and $P(z)$ (m^{-1}) is the probability density of asperity heights. This average pressure is used to induce macroscopic deformation following Boussinesq approach, the total induced displacement (summing both sides) is given by

$$u^i(x, y) = \frac{1}{\pi E^*} \text{p.v.} \int_{\mathbb{R}^2} \frac{p^i(x', y') dx' dy'}{\sqrt{(x - x')^2 + (y - y')^2}}, \quad (2)$$

where p.v. denotes principal value of the integral. Then the separation between the surfaces is updated $z_0^{i+1} = z_0^i + u$, new pressure p^{i+1} is recomputed (1) as well as the induced displacement z^{i+1} from (2). For an axisymmetric problem, a simpler form is available [2][see Eq. (3.96a)]:

$$u_z(r) = \frac{4}{\pi E^*} \int_0^{\infty} \frac{\rho}{\rho + r} p(\rho) K(k(r, \rho)) d\rho \quad (3)$$

where r and ρ are the radial coordinate and the modulus k of the complete elliptic integral of the first kind $K(k)$ is given by:

$$k(r, \rho) = \frac{4\rho r}{(r + \rho)^2}, \quad K(k) = \int_0^{\pi/2} [1 - k \sin^2(t)]^{-1/2} dt. \quad (4)$$

At the convergence separation $z^*(x, y)$, we have the information about contact area fraction, which can be computed as

$$A^*(x, y) = \pi \eta r \int_{z^*}^{\infty} (z^* - z) P(z) dz. \quad (5)$$

Example

For the set of parameters provided in Table 1, the roughness parameter [3] can be evaluated

$$\lambda = \frac{\sigma R}{a^2} \approx 0.361,$$

placing this problem in the class of problems where the deviation from the Hertz theory is significant. The iterative algorithm converges in 13 iterations for the tolerance of $\epsilon = 10^{-3}$ defined by

$$\frac{\|u_{k+1} - u_k\|_\infty}{\|u_k\|_\infty + 10^{-20}} \leq \epsilon.$$

We use some relaxation technique by weighting the obtained displacement as

$$u_{k+1} = \kappa u_{k+1} + (1 - \kappa) u_k.$$

The obtained pressure and contact area distribution are shown in Figure 1. In Figure 2 the resulting pressure, deformed configuration and the resulting surface displacement are shown.

References

1. J. A. Greenwood and J. H. Tripp (1967). *The elastic contact of rough spheres*. Journal of Applied Mechanics, **34**(1), 153–159. doi:[10.1115/1.3607616](https://doi.org/10.1115/1.3607616)
2. K. L. Johnson (1985). *Contact Mechanics*. Cambridge University Press, Cambridge. Ninth printing, 2003.
3. J. A. Greenwood, K. L. Johnson, and E. Matsubara (1984). *A surface roughness parameter in Hertz contact*. Wear, **100**(1–3), 47–57. doi:[10.1016/0043-1648\(84\)90005-X](https://doi.org/10.1016/0043-1648(84)90005-X)

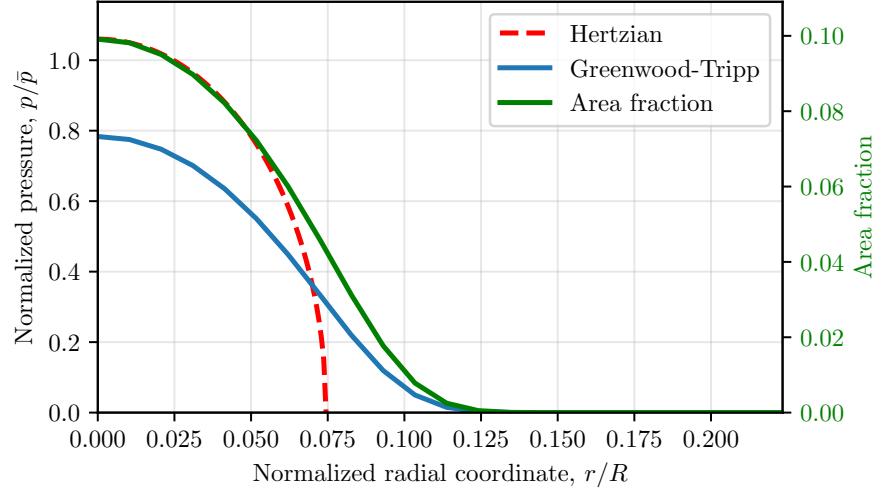


Figure 1: Pressure and true contact area distribution for rough contact compared with the Hertz solution.

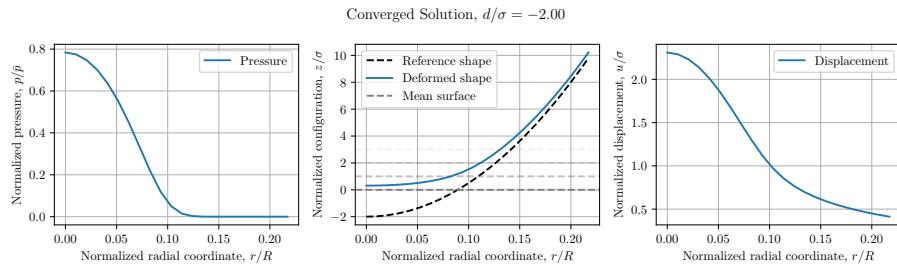


Figure 2: Converged pressure distribution (first column), initial penetration (dashed line) and the resulting indenter's configuration (middle column), converged vertical displacement.

| Parameter | Symbol | Value | Units | Description |
|-----------------------------|------------|-------------------------------|-----------------|------------------------------------|
| Material Properties | | | | |
| Young's modulus | E | 2.1×10^{11} | Pa | Steel elastic modulus |
| Poisson's ratio | ν | 0.3 | - | Poisson's ratio |
| Combined modulus | E^* | $\approx 1.15 \times 10^{11}$ | Pa | $E/(2(1 - \nu^2))$ |
| Roughness Parameters | | | | |
| RMS roughness | σ | 20 | μm | Root mean square height |
| Asperity density | η | 2×10^8 | m^{-2} | Number of asperities per unit area |
| Asperity tip radius | β | 30 | μm | Mean radius of curvature |
| Indenter Geometry | | | | |
| Type | - | Sphere | - | Indenter shape |
| Radius | R | 10 | mm | Indenter radius |
| Loading Parameters | | | | |
| Initial separation | d | -40 | μm | -2σ |
| Numerical Parameters | | | | |
| Convergence tolerance | ϵ | 10^{-3} | (-) | |
| Relaxation parameter | κ | 0.2 | (-) | |

Table 1: Model parameters