Neglecting the mass of the center-shaft (dynamically inert), determine an expression for the normal contact force \( N \) between the wheel and the ground. For this analysis, model the wheel as a hoop (bicycle tire with massless spokes) rather than as a disk. For this analysis, you will need to recall our kinematical results for this problem earlier in the quarter.
Rigid Body Analysis Template

\[ \omega = \frac{L \Omega}{R} \]

\[ \alpha = \frac{L \Omega^2}{R} + R \omega^2 = \frac{S}{\xi} \omega^2 \]

\[ \int \tan \beta = \frac{R}{L} = \frac{S}{\xi} \]

### Principal Axis Expansions

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>I's:</td>
<td>2I</td>
<td>I</td>
<td>I</td>
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</table>

### Vectors

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th>j</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{\omega} ):</td>
<td>(-\omega_c)</td>
<td>(+ \omega_s)</td>
<td>(\phi)</td>
</tr>
<tr>
<td>( \bar{H}_G = I_G(\bar{\omega}) ):</td>
<td>(- 2I \omega_c)</td>
<td>(+ I \omega_s)</td>
<td>(0)</td>
</tr>
<tr>
<td>( \bar{\omega} \times \bar{H}_G ):</td>
<td>(0)</td>
<td>(0)</td>
<td>(I \omega^2 s c)</td>
</tr>
<tr>
<td>( \bar{a} ):</td>
<td>(0)</td>
<td>(0)</td>
<td>( \frac{L \Omega^2}{R} = \frac{S}{\xi} \omega^2 )</td>
</tr>
</tbody>
</table>

### Algebra:

\[ \vec{i} \overrightarrow{C_G} = \frac{1}{2} MR^2 (sc + \xi) \omega^2 \hat{k} \]

\[ \phi = \tan \beta \]

\[ (L \omega = R) \]

\[ \frac{1}{2} ML^2 \tan \beta (\cos^2 \beta) \omega^2 \hat{k} \]
\[ \rho = L \cos \beta \]

\[ \frac{ST}{EQ} \]

\[ \frac{1}{2} ML \Omega^2 \left( 1 + \tfrac{e^2}{1+e^2} \right) \]

\[ h = R \cos \beta \]

\[ -Mg \rho + bN = (MLc \Omega^2)(Rc) + \frac{1}{2} MLR(1+e^2) \Omega^2 \]

\[ -Mg(c) + \left( \frac{1}{e} \right)N = MLR \Omega^2 \left[ c^2 + \frac{1}{2}(1+c^2) \right] \]

\[ N = Mg c^2 + \frac{1}{2} MLc \Omega^2 (1+3c^2) \]

\[ N = Mg \cos^2 \beta + \frac{1}{2} Mh (1+3 \cos^2 \beta) \Omega^2 \]

\[ \beta = \tan^{-1} \left( \frac{R}{L} \right) \]

\[ h = R \cos \beta \]