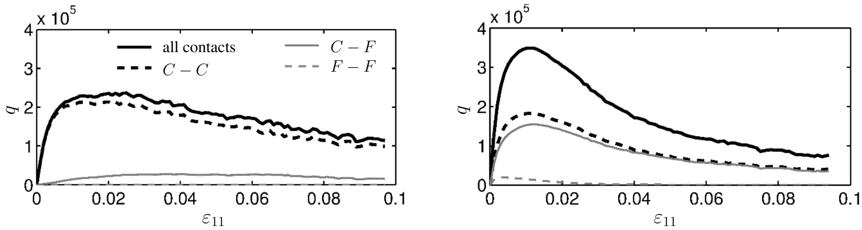
Figure 4 shows the macroscopic deviator stress q and its decomposition q^{C-C}, q^{C-F} and q^{F-F} versus axial strain ε_{11} for three fines contents $f_c = 10\%,\ 20\%$ and 30%. It can be seen that, for $f_c = 10\%$ and 20%, the applied deviatoric stress is essentially supported by contacts between coarse particles ($C-C$). However, for $f_c = 30\%$, contacts between fine and coarse particles ($C-F$) participate actively in supporting the applied deviatoric stress. The contribution of $C-F$ contacts is almost equal to that of $C-C$ contacts. The contribution of contacts between fine particles ($F-F$) is small for the studied range of f_c. It is interesting to note that q^{C-C} is almost the same whatever the fines content. Combining with the results presented in Section 4.1, we can deduce that the skeleton formed by coarse particles remains almost unchanged and its capability of supporting the external deviatoric stress remains unchanged with increasing fine content. Fine particles which surround coarse particles do not make coarse skeleton stronger. However, $C-F$ contacts take part in supporting the applied deviatoric stress. As shown in Figure 3, as fines content increases, there are more and more fine particles in contact with a coarse particle. As a result, the part of the deviatoric stress supported by $C-F$ contacts increase. This is the reason why the shear strength at high fines content is significantly higher than at low fines content as shown in Figure 2.



(a) (b)

Figure 4. *Contribution of each category of contacts $C-C$, $C-F$ and $F-F$ to the deviator stress q for different fine contents : a) $f_c = 20\%$ and b) $f_c = 30\%$.*

5. Conclusions

Despite an idealization of granular samples considered in the numerical simulation, this study has brought several insights into the micro-structure of gap-graded samples. For fines content $f_c < 20\%$, the skeleton formed by coarse particles is dominant and carries essentially the applied deviatoric stress. As a consequence, fines content does not have a significant effect on the macroscopic behavior. However, for $f_c \geq 20\%$, fine particles come into contact with coarse particles, reinforce the granular skeleton and take part in supporting the external stress, which lead to a higher shear strength.

6. Bibliographie

[Š 15] ŠMILAUER ET AL., « Yade Documentation 2nd ed », *The Yade Project. DOI 10.5281/zenodo.34073 (`http://yade-dem.org/doc/`)*, 2015.

[CHR 81] CHRISTOFFERSEN J. J., MEHRABADI M. M., NEMAT-NASSER S. S., « A Micromechanical Description of Granular Material Behavior », *Journal of Applied Mechanics*, vol. 48, n° 2, p. 339–344, 1981.

[NGU 15] NGUYEN T.-K., BENAHMED N., HICHER P.-Y., NICOLAS M., « The influence of fines content on the onset of instability and critical state line of silty sand », CHAU K.-T., ZHAO J., Eds., *Bifurcation and Degradation of Geomaterials in the New Millennium*, Springer Series in Geomechanics and Geoengineering, p. 113–120, Springer, 2015.

[SAI 11] SAIL Y. S., MAROT D., SIBILLE L., ALEXIS A., « Suffusion tests on cohesionless granular matter », *European Journal of Environmental and Civil Engineering*, vol. 15, n° 5, p. 799–817, 2011.

[SAL 00] SALGADO R., BANDINI P., KARIM A., « Shear strength and stiffness of silty sand », *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, vol. 126, n° 5, p. 451–462, 2000.

[THE 02] THEVANAYAGAM S., SHENTHAN T., MOHAN S., LIANG J., « Undrained Fragility of Clean Sands, Silty Sands, and Sandy Silts », *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, vol. 128, n° 10, p. 849–859, 2002.