Closure to **"Effect of Rubber Crumbs on the Cyclic Behaviour of Steel Furnace Slag and Coal Wash Mixtures" by** Yujie Qi[1]; Buddhima Indraratna[2], F.ASCE; Ana Heitor[3]; and Jayan S. Vinod[4], A.M. ASCE; DOI: 10.1061/(ASCE)GT.1943-5606.0001827

Response to Discussion:

The authors appreciate the comments made by the Discusser, and for providing an opportunity to further clarify the effect of volumetric expansion of steel furnace slag on the waste matrix, as elaborated below:

The authors have developed a synthetic energy absorbing layer for subballast by optimizing the SFS+CW+RC mixtures, and the property of this matrix has been published earlier by Indraratna et al. (2018). The main detrimental factor of steel furnace slag (SFS) is its volume expansion that can cause damage to infrastructure. Therefore, when optimizing SFS+CW+RC mixtures to serve as subballast, the swell pressure must be considered as one of a key parameter. The blending ratio of SFS:CW which governs the shear strength and the swelling characteristic was optimized to be 7:3 based on the test results including the friction angle and swell pressure (Indraratna et al. 2018). It was found that for the blending ratio SFS:CW=7:3, this matrix had less volumetric expansion while maintaining sufficient shear strength.

[1] PhD, Research Associate, Centre for Geomechanics and Railway Engineering, University of Wollongong (CGRE), ARC Industry Transformation Training Centre for Advanced Rail Track Technologies (ITTC-Rail), School of Civil, Mining & Environmental Engineering, University of Wollongong, Wollongong City, NSW 2522, Australia, e-mail: qyujie@uow.edu.au
[2] Distinguished Professor of Civil Engineering and Research Director, Centre for Geomechanics and Railway Engineering (CGRE), ARC Industry Transformation Training Centre for Advanced Rail Track Technologies (ITTC-Rail), University of Wollongong, Wollongong City, NSW 2522, Australia, e-mail: indra@uow.edu.au
[3] Senior Lecturer, Centre for Geomechanics and Railway Engineering (CGRE), ARC Industry Transformation Training Centre for Advanced Rail Track Technologies (ITTC-Rail), School of Civil, Mining & Environmental Engineering, University of Wollongong, Wollongong City, NSW 2522, Australia, e-mail: aheitor@uow.edu.au
[4] Associate Professor, Centre for Geomechanics and Railway Engineering (CGRE), ARC Industry Transformation Training Centre for Advanced Rail Track Technologies (ITTC-Rail), School of Civil, Mining & Environmental Engineering, University of Wollongong, Wollongong City, NSW 2522, Australia, e-mail: vinod@uow.edu.au

The influence of RC content (R_b, %) on the expansive characteristics of the waste matrix was also investigated by the authors, as presented in Fig.1. The swell pressure test results show that the addition of RC can reduce the swell pressure (P_{swell}). This is attributed to the volumetric expansion generated by SFS that is partially counteracted when the RC particles deform (compress). Moreover, when $R_b \geq 10$, the reduction in P_{swell} is marginal, and the swell pressure of the waste matrix is significantly less than the minimum vertical stress on the subballast, see Fig.1 (Trani and Indraratna 2010; Indraratna et al. 2011). Therefore, the vertical expansion of SFS will not be able to cause any structural damage to concrete cross ties.

The authors agree with the possibility that the swell pressure of SFS may reduce the effective confining pressure working on the subballast layer and induce more lateral displacement. However, the confining pressure for subballast layer that mainly generates from the shoulder ballast is ≤ 40 kPa (Indraratna et al. 2011) which is greater than P_{swell} of the waste matrix having $R_b = 10\%$. Therefore, the swelling of the waste matrix would not be a major concern.

It is important to note that the swell pressure tested by the authors may not necessarily applicable to all types of SFS, as the geotechnical properties of this waste material can vary significantly according to their original source and manufacturing process (Chiaro et al. 2013). Therefore, when including SFS into the waste mixtures, the swell pressure of the matrix needs to be examined carefully.

References:

Chiaro, G., Indraratna, B., Tasalloti, S.M.A. and Rujikiatkamjorn, C. (2015). "Optimisation of coal wash-slag blend as a structural fill." *Ground Improvement*, 168(GI1), 33-44.

Indraratna, B., Salim, W. and Rujihiatkamjorn, C. (2011). *Advanced rail geotechnology-ballasted track*, CRC Press, London.

Indraratna, B., Qi, Y., and Heitor, A. (2018). "Evaluating the Properties of Mixtures of Steel Furnace Slag, Coal Wash, and Rubber Crumbs Used as Subballast." *J. Mater. Civil Eng.*, 30(1), 04017251.

Trani, L.D.O. and Indraratna, B. (2010). "Experimental investigations into subballast filtration behavior under cyclic loaging." *Australian Geomechanics*, 45(3), 123-133.

Figure list

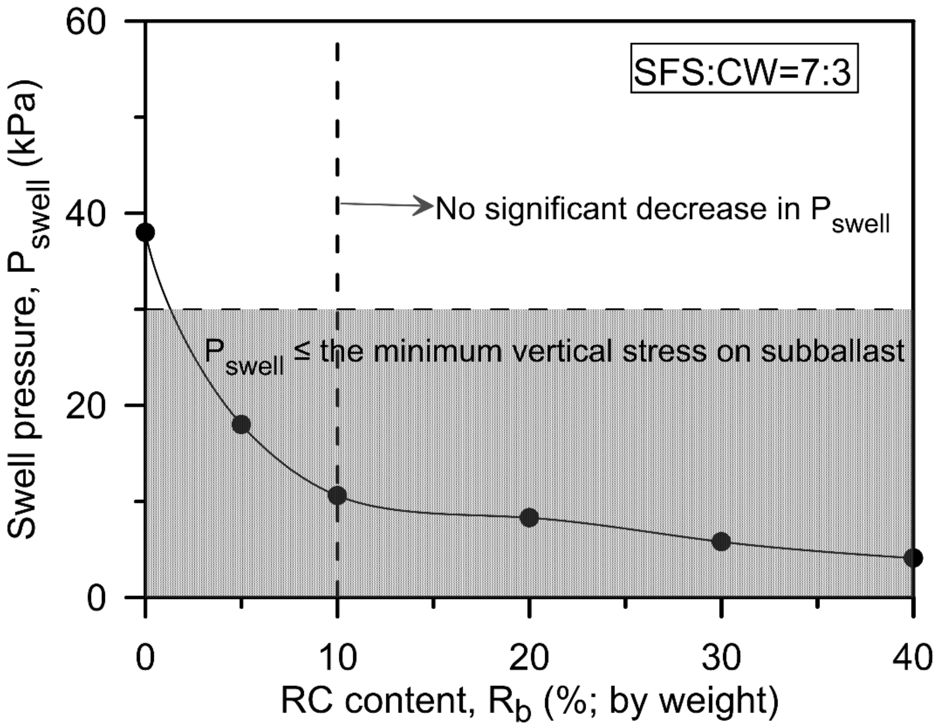

Fig.1 Swell pressure of SFS+CW+RC mixtures varying with different RC contents (modified after Indraratna et al. 2018)