Supplementary

Table S1. Details on an example of the particle size fractions modeled for crushing process.

Sieve Size	Initial PSF (Q[a])	Crushing		Crushed fragment							Total Change[g]	Modeled PSF	Observed PSF (U–I–H[h])	Diff[2i]
				Rate[d]			Point							
				Crushing Particle Size Diameter/Sieve Size (mm)										
		Rate[b]	Point	19.0	12.7	4.76	19.0	12.7	4.76	Total				
(mm)	(%)	(%/%)	(%)	(%/%)	(%/%)	(%/%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%^{2})
38.1	0										0	0	0	0
19.0	10.89	−0.80	−8.71[c]								−8.71	2.18	2.80	0.39
12.7	11.58	−0.40	−4.63	0.14[e]			1.21[f]			1.21	−3.42	8.16	8.36	0.04
4.76	40.86	−0.20	−8.17	0.31	0.33		2.73	1.53		4.26	−3.91	36.94	39.08	4.57
2.38	11.24			0.18	0.20	0.24	1.57	0.94	1.93	4.45	4.45	15.69	14.93	0.58
0.595	10.20			0.23	0.28	0.40	2.04	1.31	3.24	6.60	6.60	16.80	14.44	5.55
0.074	6.01			0.12	0.16	0.30	1.02	0.73	2.42	4.17	4.17	10.17	8.40	3.13
<0.074	9.23			0.02	0.03	0.07	0.14	0.12	0.58	0.83	0.83	10.07	11.99	3.68
Sum	100.00		−21.51	1.00	1.00	1.00	8.71	4.63	8.17	21.51	0	100.00	100.00	17.95

[a] The PSFs from the quarry were used for the model. [b] Rock strength increases with decreasing particle size [28–30,34]. Therefore, we assumed that large-size particles were more likely crushed and small-size particles (≤2.38 mm) were not. We used arbitrary crushing rates, −0.80, −0.40, and −0.20, for the large-size particles, 19.0, 12.7, and 4.76 mm diameters, for the model, resulting in a total of −21.51 percentage points change. [c] Initial PSF for 19.0 mm (10.89%) × crushing rate for 19.0 mm (−0.80) = crushing point for 19.0 mm (−8.71%). [d] Crushed fragment size distribution could be described using a truncated logarithmic normal distribution by mass [33]. For the crushed fragment size distribution, we used a half-logarithmic normal distribution with a mean of the crushed particle diameter (sieve size) and a standard deviation of 10.0 mm. [e] The rate of the crushed fragments in mass, of which particle size was between 19.0 and 12.7 mm, from crushing 19.0 mm particles (R_{cf}(19.0, 10.0, 19.0, 19.0, 12.7)) = the probability between 19.0 and 12.7 mm in the logarithmic normal distribution with a mean of 19.0 mm and a standard deviation of 10.0 mm divided by 0.5 (probability of a half normal distribution) = $\int_{\log 12.7}^{\log 19.0} \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-log19.0)^2}{2}} dx/0.5$. [f] Crushing point for 19.0 mm (8.71%) × crushed fragment rate for 12.7 mm from crushing 19.0 mm particles (0.14) = crushed fragment point for 12.7 mm from crushing 19.0 mm particles (1.21%). [g] Total change = crushing point + total point from crushed fragment. [h] The observed PSF was based on the PSFs at U–I–H [11], where the crushing process occurred. [i] Difference^2 = (Observed PSF − Modeled PSF)^2.

Table S2. Details on an example of the particle size fractions modeled for subgrade mixing process.

Sieve Size	Initial PSF (Q[a])	Change[b]	Modeled PSF		Observed PSF (B–S–H[d])	Diff^2[e]
(mm)	(%)	(%)	(%)	(%)	(%)	(%^{2})
38.1	0		0	0	0	0
19.0	10.89		10.89	8.38[c]	3.26	26.13
12.7	11.58		11.58	8.90	6.38	6.36
4.76	40.86		40.86	31.43	34.05	6.89
2.38	11.24		11.24	8.65	14.57	35.11
0.595	10.20	10.00	20.20	15.54	15.37	0.03
0.074	6.01	10.00	16.01	12.31	9.85	6.08
<0.074	9.23	10.00	19.23	14.80	16.51	2.93
Sum	100.00	30.00	130.00	100.00	100.00	83.52

[a] The PSFs from the quarry were used for the model. [b] We assumed that the subgrade mixing process added 10 percentage points to each of 0.595, 0.074, and less than 0.074 mm sieve sizes, resulting in a total of 30 percentage points change. [c] 10.89/130.00 = 8.38%. [d] The observed PSF was based on the PSFs at B–S–H [11], where the subgrade mixing process occurred. [e] Difference^2 = (Observed PSF − Modeled PSF)^2.

Table S3. Details on an example of the particle size fractions modeled for sweeping process.

Sieve Size	Initial PSF (Q[a])	Sweeping-Out			Sweeping-In				
		Change[b]	Modeled PSF		Change[d]	Modeled PSF		Observed PSF (U–S–L[f])	Diff^2[g]
(mm)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%^{2})
38.1	0		0	0		0	0	0	0
19.0	10.89	−10.00	0.89	1.27[c]	20.00	30.89	19.31[e]	10.20	82.97
12.7	11.58	−10.00	1.58	2.25	20.00	31.58	19.73	15.76	15.82
4.76	40.86	−10.00	30.86	44.08	20.00	60.86	38.04	47.09	81.98
2.38	11.24		11.24	16.06		11.24	7.03	10.30	10.70
0.595	10.20		10.20	14.57		10.20	6.37	6.70	0.11
0.074	6.01		6.01	8.58		6.01	3.75	4.10	0.12
<0.074	9.23		9.23	13.19		9.23	5.77	5.87	0.01
Sum	100.00		70.00	100.00	0	160.00	100.00	100.00	191.70

[a] The PSFs from the quarry were used for the model. [b] We assumed that the sweeping-out process subtracted 10 percentage points to each of 19.0, 12.7, and 4.76 mm sieve sizes, resulting in a total of −30 percentage points change. [c] 0.89/70.00 = 1.27%. [d] We assumed that the sweeping-in process added 20 percentage points to each of 19.0, 12.7, and 4.76 mm sieve sizes, resulting in a total of 60 percentage points change. [e] 30.89/160.00 = 19.31%. [f] The observed PSF was based on the PSFs at U–S–L (Rhee et al., in review), where the sweeping-in process occurred. [g] Difference^2 = (Observed PSF − Modeled PSF)^2.

Table S4. Details on the particle-size fractions that are fitted to the particle size distribution result for crushing process.

Sieve Size	Initial PSF (Q[a])	Crushing		Crushed fragment							Total change[g]	Modeled PSF	Observed PSF (U–I–H[h])	Diff[2i]
		Rate[b]	Point	Rate[d]			Point							
				Crushing Particle Size Diameter/Sieve Size (mm)										
				19.0	12.7	4.76	19.0	12.7	4.76	Total				
(mm)	(%)	(%/%)	(%)	(%/%)	(%/%)	(%/%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%²)
38.1	0										0	0	0	0
19.0	10.89	−0.73	−7.97[c]								−7.97	2.91	2.80	0.01
12.7	11.58	−0.33	−3.88	0.10[e]			0.79[f]			0.79	−3.09	8.49	8.36	0.02
4.76	40.86	−0.11	−4.40	0.23	0.24		1.85	0.92		2.77	−1.63	39.23	39.08	0.02
2.38	11.24			0.15	0.16	0.17	1.18	0.61	0.74	2.53	2.53	13.77	14.93	1.33
0.595	10.20			0.24	0.26	0.31	1.88	1.01	1.36	4.26	4.26	14.45	14.44	<0.01
0.074	6.01			0.20	0.23	0.32	1.58	0.90	1.42	3.90	3.90	9.91	8.40	2.27
<0.074	9.23			0.09	0.11	0.20	0.69	0.44	0.88	2.01	2.01	11.24	11.99	0.56
Sum	100.00		−16.25	1.00	1.00	1.00	7.97	3.88	4.40	16.25	0	100.00	100.00	4.20

[a] The PSFs from the quarry were used for the model. [b] Rock strength increases with decreasing particle size [28–30,34]. Therefore, we assumed that large-size particles were more likely crushed and small-size particles (≤ 2.38 mm) were not. We found that the crushing rates, −0.73, −0.33, and −0.11, for the large-size particles, 19.0, 12.7, and 4.76 mm diameters, resulted in a total of −16.25 percentage points and a close match to the PSFs at U–I–H, where the crushing process occurred [11]. [c] Initial PSF for 19.0 mm (10.89%) × crushing rate for 19.0 mm (−0.73) = crushing point for 19.0 mm (−7.97%). [d] Crushed fragment size distribution could be described using a truncated logarithmic normal distribution by mass [33]. For the crushed fragment size distribution, we found that a half-logarithmic normal distribution with a mean of the crushed particle diameter (sieve size) and a standard deviation of 25.6 mm resulted in a close match to the PSFs at U–I–H, where the crushing process occurred [11]. [e] The rate of the crushed fragments in mass, of which particle size is between 19.0 and 12.7 mm, from crushing 19.0 mm particles (R_{cf}(19.0, 25.6, 19.0, 19.0, 12.7)) = the probability between 19.0 and 12.7 mm in the logarithmic normal distribution with a mean of 19.0 mm and a standard deviation of 25.6 mm divided by 0.5 (probability of a half normal distribution) = $\int_{\log 12.7}^{\log 19.0} \frac{1}{\sqrt{2\pi}\cdot log25.6} e^{-\frac{(x-log19.0)^2}{2(log25.6)^2}} dx/0.5$. [f] Crushing point for 19.0 mm (7.97%) × crushed fragment rate for 12.7 mm from crushing 19.0 mm particles (0.10) = crushed fragment point for 12.7 mm from crushing 19.0 mm particles (0.79%). [g] Total change = crushing point + total point from crushed fragment. [h] The observed PSF was based on the PSFs at U–I–H [11], where the crushing process occurred. [i] Difference² = (Observed PSF − Modeled PSF)².

Table S5. Details on the particle-size fractions that are fitted to the particle size distribution results for subgrade mixing process.

Sieve Size	Observed PSF (B–S–H[a])	Using PSD from the Quarry					Using PSD After Crushing				
		Initial PSF (Q[b])	Change[c]	Modeled PSF		Diff^2[e]	Initial PSF (U–I–H[f])	Change[g]	Modeled PSF		Diff^2[g]
(mm)	(%)	(%)	(%)	(%)	(%)	(%^{2})	(%)	(%)	(%)	(%)	(%^{2})
38.1	0	0		0	0	0	0		0	0	0
19.0	3.26	10.89		10.89	8.16[d]	24.01	2.80		2.80	2.43	0.69
12.7	6.38	11.58		11.58	8.68	5.27	8.36		8.36	7.26	0.78
4.76	34.05	40.86		40.86	30.63	11.70	39.08		39.08	33.94	0.01
2.38	14.57	11.24	6.94	18.18	13.63	0.89	14.93	1.87	16.80	14.59	<0.01
0.595	15.37	10.20	9.05	19.24	14.43	0.89	14.44	3.28	17.72	15.39	<0.01
0.074	9.85	6.01	5.87	11.87	8.90	0.89	8.40	2.95	11.35	9.86	<0.01
<0.074	16.51	9.23	11.52	20.75	15.56	0.89	11.99	7.04	19.02	16.52	<0.01
Sum	100.00	100.00	33.37	133.37	100.00	44.55	100.00	15.13	115.13	100.00	1.48

[a] The observed PSF was based on the PSFs at B–S–H [11], where the subgrade mixing process occurred. [b] The PSFs from the quarry were used for the model. [c] We found that adding 6.94, 9.05, 5.87, and 11.52 percentage points (a total of 33.37 percentage points) to 2.38, 0.595, 0.074, and less than 0.074 mm sieve sizes resulted in the PSFs that minimize the differences from the PSFs at B–S–H. [d] 10.89/133.37 = 8.16%. [e] Difference^2 = (Observed PSF − Modeled PSF)^2. [f] The PSFs at U–I–H, where the crushing process occurred [11] were used for the model. The PSFs for 2.38 and 0.595 mm were linearly interpolated using the PSFs at U–I–H for 3.36, 2.00, 1.00, and 0.420 mm. [g] We found that adding 1.87, 3.28, 2.95, and 7.04 percentage points (a total of 15.13 percentage points) to 2.38, 0.595, 0.074, and less than 0.074 mm sieve sizes resulted in a close match to the PSFs at B–S–H.

Table S6. Details on the particle size fractions that are fitted to the particle size distribution results for sweeping-in process.

Sieve Size	Initial PSF (Q[a])	Change [b]	Modeled PSF		Observed PSF (U–S–L[d])	Diff^{2} [e]
(mm)	(%)	(%)	(%)	(%)	(%)	(%^{2})
38.1	0		0	0	0	0
19.0	10.89	4.72	15.61	10.21[c]	10.20	<0.01
12.7	11.58	12.54	24.12	15.77	15.76	<0.01
4.76	40.86	31.20	72.06	47.10	47.09	<0.01
2.38	11.24	4.53	15.77	10.31	10.30	<0.01
0.595	10.20		10.20	6.67	6.70	<0.01
0.074	6.01		6.01	3.93	4.10	0.03
<0.074	9.23		9.23	6.04	5.87	0.03
Sum	100.00	53.00	153.00	100.00	100.00	0.06

[a] The PSFs from the quarry were used for the model. [b] We found that adding 4.72, 12.54, 31.20, and 4.53 percentage points (a total of 53.00 percentage points) to 19.0, 12.7, 4.76, and 2.38 mm sieve sizes resulted in a close match to the PSFs at U–S–L, where the sweeping-in process occurred [11]. [c] 15.61/153.00 = 10.21%. [d] The observed PSF was based on the PSFs at U–S–L [11], where the sweeping-in process occurred. [e] Difference^{2} = (Observed PSF − Modeled PSF)^{2}.

Table S7. Comparison of the modified model parameter values and the logarithmic normal distribution for sweeping-in process.

Sieve Size	Change [a]		F(j)–F(k) [c]	Diff^{2} [e]
(mm)	(%)	(%)	(%)	(%^{2})
38.1			0.58	0.33
19.0	4.72	8.91[b]	10.70	3.18
12.7	12.54	23.67	21.31	5.57
4.76	31.20	58.87	59.36	0.24
2.38	4.53	8.54	7.71	0.68
0.595			0.34	0.11
0.074			<0.01	<0.01
<0.074			<0.01	<0.01
Sum	53.00	100.00	100.00	10.11

[a] We found that adding 4.72, 12.54, 31.20, and 4.53 percentage points (a total of 53.00 percentage points) to 19.0, 12.7, 4.76, and 2.38 mm sieve sizes resulted in a close match to the PSFs at U–S–L, where the sweeping-in process occurred [11]. [b] 4.72/53.00 = 8.91%. [c] F is the cumulative distribution function of the logarithmic normal distribution with a mean of 10.0 mm and a standard deviation of 1.70 mm. F(j)–F(k) is the probability between the sieve sizes of j and k mm in the logarithmic normal distribution. [d] Difference^{2} = (Observed PSF − Modeled PSF)^{2}.