ROCKFILL TEST FILL TO DETERMINE THE IMPACT OF COMPACTION PASSES ON ROCKFILL SETTLEMENTAND TO COMPARE DRY DENSITY AFTER 6 AND 8 PASSES IN EL LLAGAL TAILINGS DAM

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ABSTRACT

El Llagal tailings dams, located in Pueblo Viejo mine, Dominican Republic, are designed as water-retaining structure with a low-permeability core, two-stage granular filters, and rockfill shells. The source for rockfill was quarried (drill and blasted) limestone rock. The rock produced at the quarry had an inconsistent grain-size due to the structural nature of the limestone body, where a blast could easily have particle size larger than 1000 mm along with piles of sand and gravel. The limestone in the quarry also had weathered zones that are comprised of residual soil with significant fines content.The rockfill for dam fill material was selected and grain sized evaluated at the source prior delivery to the dam. This technical work describes a test fill performed to determine the impact of compaction passes on rockfill settlement, compare the rockfill dry density after 6 and 8 passes, and validate construction techniques representative of those detailed in the technical specifications used in the construction of the dams.

1. INTRODUCTION

The Pueblo Viejo Projectis located in central Dominican Republic, approximately 55 km north northwest of the capital city, Santo Domingo. The El Llagal tailings storage facility (LL TSF) is the operational tailings and waste rock storage facility for the Pueblo Viejo Mine. It is located approximately 3.5 km south of the mine plant site. The final crest elevation of the LL TSF is designed to be 265 m that provides a total waste storage volume of 225 Mm^3 (i.e. waste and operating pond, excluding freeboard and storm event storage), with storage volume provided by Lower Llagal (LL) Dam and three associated saddle dams (SDs). LL Dam(155 m dam height) was designed as water-retaining structure with a low-permeability core, two-stage granular filters, and rockfill shells consisting of non-acid generating, durable rock. The total earth-fill volume for the LL TSF dams at El. 265 m would be approximately 22Mm^3. The total rockfill volume would be approximately 15Mm^3.This technical work describesgeneral procedures and execution of a rockfill test fill performed to determine the impact of compaction passes on rockfill settlement, compare the rockfill dry density after 6 and 8 passes, including excavation volume determined by water replacement and scanning survey techniques, and validate construction techniques representative of those detailed in the technical specifications used in the LL Dam construction.

1.1 General dam design information

All El Llagal TSF dams are designed as tailings and water retention dams with low-permeability fill (LPF) cores, filter zones downstream of the core, crack stopper zones upstream of the core, and rockfill shells consisting of non-acid generating, durable rock. LL Dam upstream slope is 1.5H:1V, and the downstream slope is 1.7H:1V. Four primary materials are used to construct the TSF structures: LPF, granular filters, rockfill and waste limestone (i.e. rockfill with higher fines content up to 35%).Figure 1 shows a representative LL Starter Dam (LLSD) cross section.

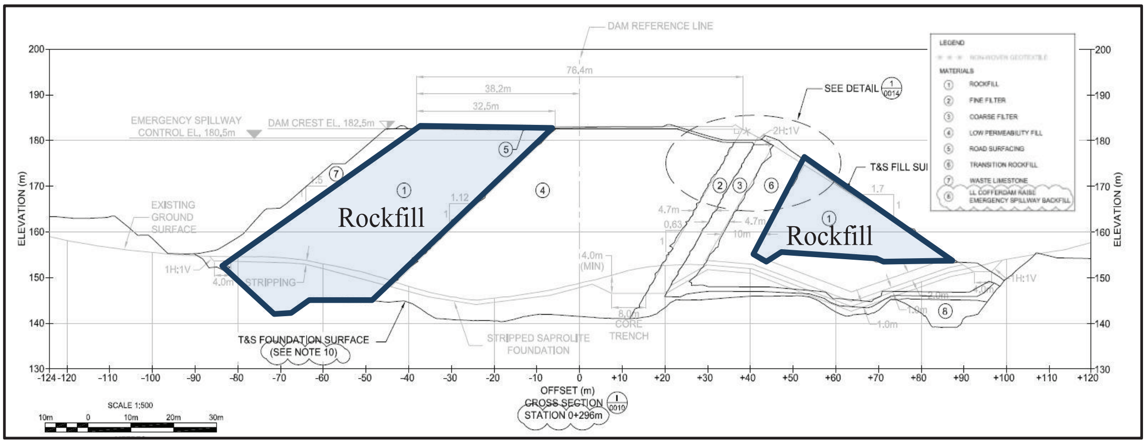

Figure 1 : Representative cross section of LLSD.

1.2 Rockfill strength parameters

The primary purpose of the rockfill zone in the dams is to support the LPF core in all anticipated loading conditions. The coarseness of the rockfill means that a zone of transition rockfill is needed between the rockfill and coarse filter.As the quarried limestone for use as a rockfill is to provide a zone that, as much as practical, had low compressibility and high shear strength, a key factor in achieving these requirements was maintaining good drainage in the rockfill, especially during periods of flooding or severe earthquake shaking. The rockfill must also be dense, durable, chemically inert and free of defects which would reduce its resistance to water or atmospheric deterioration. Material strength for rockfill is summarized in Table 1.

Table 1 : Material strength for rockfill.

Material	Unit Weight (kN/m^3)	Effective Stress Strength	Source	Undrained Strength Cyclic
Rockfill	22	Average Leps Strength Curve [1]	Literature	N/A

(1) Leps (1970)

1.3 Material and compaction requirements in technical specifications

The following are material and compaction requirements as per construction technical specifications:

- Maximum particle size: 1000 mm (grain size distribution by a combination of ASTM D5519 and D6913).
- Fines content no greater than 3%.
- Los Angeles abrasion test (ASTM C535, Gradation 3): weight loss less than 45%.
- Specific gravity (ASTM C127): greater than 2.6.
- Soundness (ASTM C88): weight loss than 12% after 5 cycles.
- Compaction requirements:
  - A minimum 18t single, smooth drum vibratory roller.
  - As-placed moisture content's ratio of water to rock 0.2:1 by volume.
  - Maximum lift thickness before compaction of 1500 mm.
  - Minimum passes of compactor per lift of 8 passes.

2. TEST FILL EXECUTION

2.1 Test fill preparation

The rockfill test fill was completed on a rockfill compacted lift of 20 m by 16.5 m leveled platform within the upstream rockfill shell of the El Llagal Starter Dam (LLSD). Figure 2 shows the layout of the test fill site. Photograph 1shows rockfill test fill subgrade.

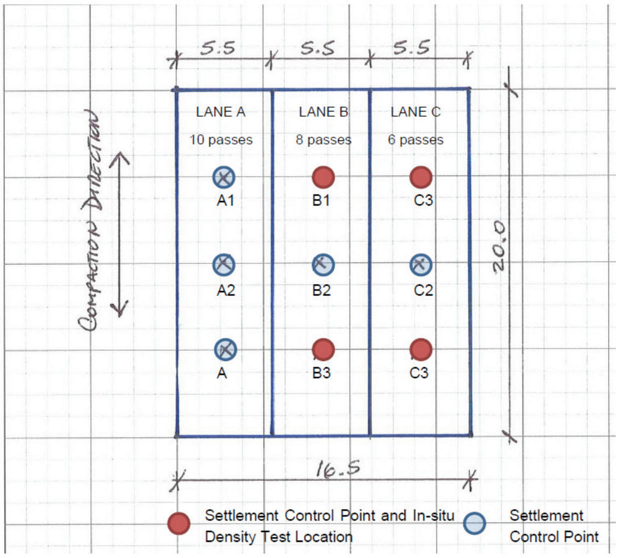

Figure 2 : Rockfill test fill layout.

Photograph 1 : Test fill subgrade before rockfill placement.

2.2 Test fill execution

Construction management coordinated and provided the resources to carry out the test fill. The following heavy equipment was used:

- A smooth drum vibratory roller Ingersoll Rand SD-200D TF Series. The roller operating weight was 20.4 tonnes and vibratory frequency was 1850 per minute.
- A CAT D8 Bulldozer
- Water trucks (3000, 4000, and 5000-gallon capacity)
- A front-end loader
- A backhoe

The test fill subgrade was surveyed to provide the basis for subsequent settlement measurements. As shown in Figure 2, nine reference stations were established (three per lane). Construction techniques were representative of those used during regular rockfill placement. Rockfill was delivered and place over the entire test fill area at an average thickness of 1.62 m. Elevation at each reference station was surveyed, and water was applied using water trucks prior compaction.

Compaction was carried out in two pass increments, with watering and surveying being repeated every two passes until the desired number of passes was achieved, as shown in Figure 2. The volume of applied water was targeted to be a total of 20% of the rockfill volume. Upon completion of the required number of passes, in-situ rockfill density testing was completed at four locations. Photograph 2 shows water application on rockfill.

Photograph 2 : Water application on rockfill and compaction.

At each location, a 2.5 m diameter steel ring was placed on the compacted rockfill surface to act as a guide for the backhoe. The backhoe carefully removed rockfill from within the limits of the ring to create a hole. The weight of the removed rockfill was measured by quality control personnel. The volume of each excavated hole was measured using two methods: water replacement and scanning survey. In the water replacement method, quality control personnel placed a plastic membrane into the excavation and measured the volume of water required to fill the hole. In the scanning survey method, mine operation survey personnel used specialized equipment to form a 3D model of each hole for later volume determination. Photograph 3, 4 and 5 show a sequence of excavation and volume determination by two techniques.

Photograph 3 : Backhoe excavation within steel ring for density tests.

Photograph 4 : Filling density test excavation to determine volume using the water replacement method.

Photograph 5 : Excavation volume determination by scanning survey method.

Samples were collected by quality control personnel for laboratory testing (i.e. grain size distribution, moisture content, specific gravity, and Los Angeles abrasion tests), as show in Photograph 6.

Photograph 6 : The bagged rockfill material weighed by quality control personnel.

3. TEST FILL RESULTS

3.1 Permeability

Visual observation of rockfill performance after watering showed that ruts on surface were not significant under truck tires or compaction equipment, and that added water quickly percolated into the rockfill. These observations indicate that the LLSD rockfill behaves as a free-draining material. This is also supported by grain size test results discussed below.

3.2 Settlement

For the purpose of this test fill, the subgrade material (i.e. already constructed LLSD upstream rockfill shell material) was assumed to be incompressible relative to the test fill material. The elevation of the subgrade at each reference measurement location was assumed to stay constant. Settlement was measured after every two passes, as shown in Table 2 and plotted in Figure 3.

Figure 3 shows the expected general trends of increasing settlement with the number of passes, with the most settlement occurring in the initial two passes. For all lanes, 50% to 60% of the ultimate recorded settlement was achieved after the first two passes. Lanes A and C (10 and 6 passes, respectively) exhibited similar behavior, both in the rate and magnitude of observed settlements. However, Lane B (8 total passes) showed significantly less total settlement after application of similar compactive energy.

Table 2 : Rockfill settlement data.

Lane	Point	Loose lift thickness (m)	Incremental settlement (mm) after # passes					Cumulative settlement (mm) After # passes				
			2	4	6	8	10	2	4	6	8	10
A	A1	1.59	80	22	18	7	10	80	102	120	127	137
	A2	1.64	102	29	23	5	5	102	131	154	159	164
	A3	1.60	77	30	9	10	9	77	107	116	126	135
Average		1.61	86	27	17	7	8	86	113	130	137	145
B	B1	1.53	44	3	33	4	-	44	47	80	84	-
	B2	1.59	46	3	28	0	-	46	49	77	77	-
	B3	1.62	57	3	19	6	-	57	60	79	85	-
Average		1.58	49	3	27	3	-	49	52	79	82	-
C	C1	1.64	75	14	29	-	-	75	89	118	-	-
	C2	1.63	47	27	29	-	-	47	74	103	-	-
	C3	1.73	98	41	20	-	-	98	139	159	-	-
Average		1.67	73	27	26	-	-	73	101	127	-	-

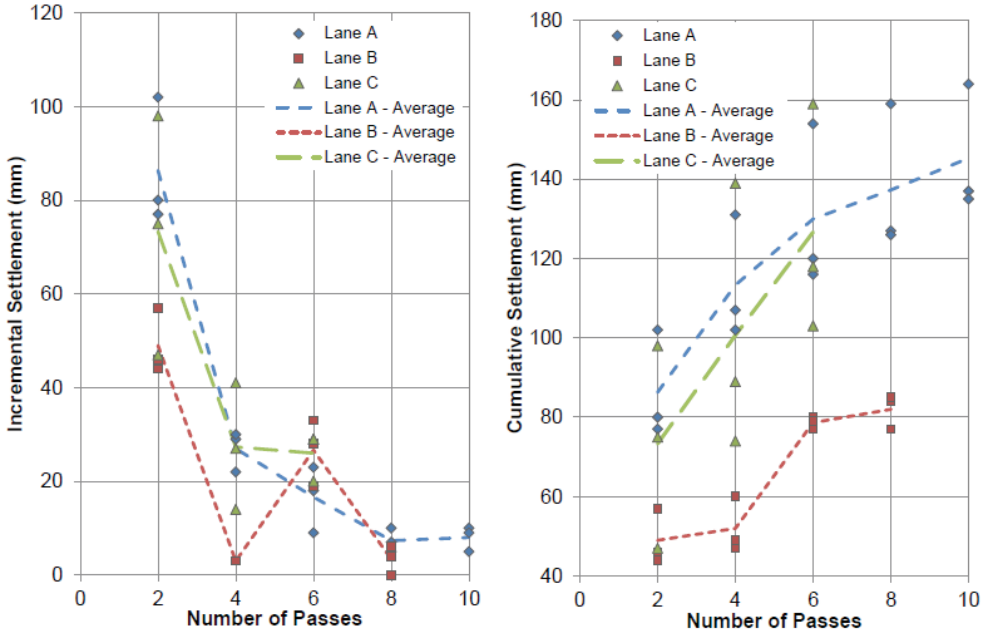

Figure 3 : Rockfill settlement observations.

3.3 In-situ density

In-situ density tests were performed at two locations in each Lanes B and C, as illustrated in Figure 1. Excavation volumes were determined by both a water replacement method and scanning survey method as described in section 2.2. The test results are summarized in Table 3 and Figure 4 below.

Table 3 : In-situ density test results.

Control Point	Volume (water replacement) (m^3)	Volume (scanning survey) (m^3)	Dry density (water replacement) (kg/m^3)	Dry density (scanning survey) (kg/m^3)
B1 (8 passes)	6.94	6.61	2100	2205
B3 (8 passes)	8.29[1]	6.20[1]	1729[2]	2314
C1 (6 passes)	8.12	7.67	2068	2190
C3 (6 passes)	6.80	6.80	2063	2062

(1) Volumes measured at location B3 do not show consistent results. Quality control noted a possible flow meter reading error during testing.

(2) Corresponding dry density result discarded.

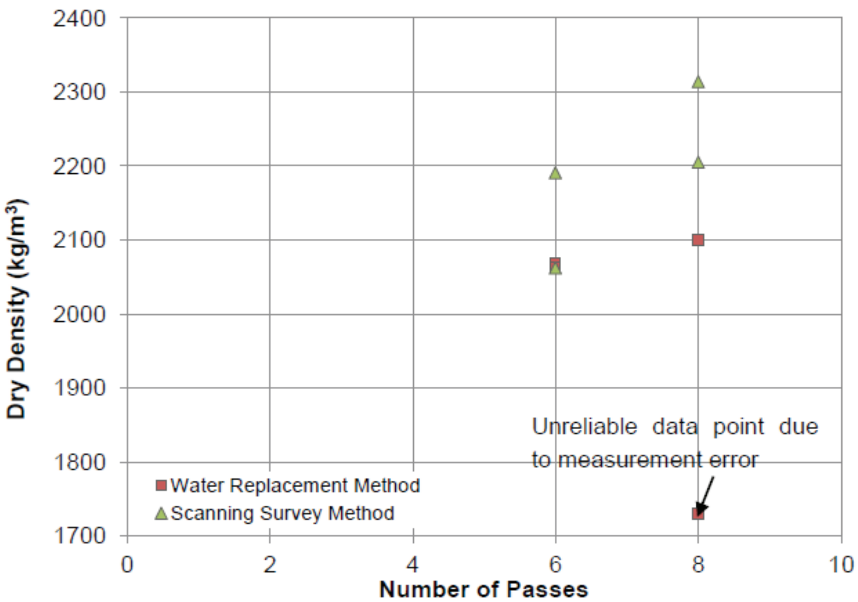

Figure 4 : Relationship between measured dry density and compaction effort.

3.4 Laboratory testing

The laboratory testing program consisted of four moisture content tests, four grain size distribution tests, three Los Angeles abrasion tests, and three specific gravity tests. The tests were completed on samples collected at locations B1, B3, C1 and C3 (i.e. the locations of the in-situ density tests). The lab testing results are summarized in Table 4.

Table 4 : Rockfill laboratory testing results.

Control point	Moisture content (%)	Grain Size				LA abrasion loss (%)	Bulk specific gravity
		% cobbles & boulders	% Gravel	% Sand	% Fines		
B1 (8 passes)	1.8	53	35	8	4	42	2.63
B3 (8 passes)	1.5	49	41	7	3	41	2.65
C1 (6 passes)	1.5	37	48	12	3	-	-
C3 (6 passes)	2.9	49	40	8	3	40	2.61

4. CONCLUSIONS

4.1 Settlement

In general, settlement increases with increasing number of compaction passes. However, the magnitude of settlement induced after each compactor pass decreases with increased compactive effort. Assuming that the final measured settlement in Lane A (10 total passes) represents the ultimate expected settlement, 59% of settlement has occurred after two passes, and 94% of settlement has occurred after 8 passes. Between 8 passes and 10 passes, settlement increased by 8 mm. Thus, the number of passes (eight) required by the technical specifications fulfills the design intent of optimizing the applied compactive effort while minimizing potential for large future settlement.

4.2 Density

As determined by scanning survey, the average rockfill dry density reached after 6 and 8 passes is 2,126 kg/m^3 and 2,260 kg/m^3, respectively. The average rockfill dry density measured by water replacement after 6 passes is 2,066 kg/m^3. Dry density calculated using the water replacement method at control point B3 is not reliable due to an inaccurate volume determination caused by flow meter reading error, preventing an average density from being reported for the 8 passes case.

As expected, rockfill dry density was observed to increase with an increasing number of compactor passes. Also, the scanning survey volume measurement method was noted to provide higher densities than the water replacement measurement method.

4.3 Permeability

A water volume equivalent to 20% of the rockfill volume was applied during the compaction process. Visual observation noted that ruts were no significant under truck tires or compaction equipment, and that water quickly percolated into the rockfill. Combined with the grain size test results showing 3 to 4% fines content, this illustrates that the LLSD rockfill is free-draining, in conformance with the design intent.

REFERENCE

Leps, T.M., 1970. Review of shearing strength of rockfill. Journal of soil mechanics and foundation division, ASCE 96 (SM4), pp 1159-1170.