Underground Shotcrete Roof Repair of Hanging Lake Tunnel

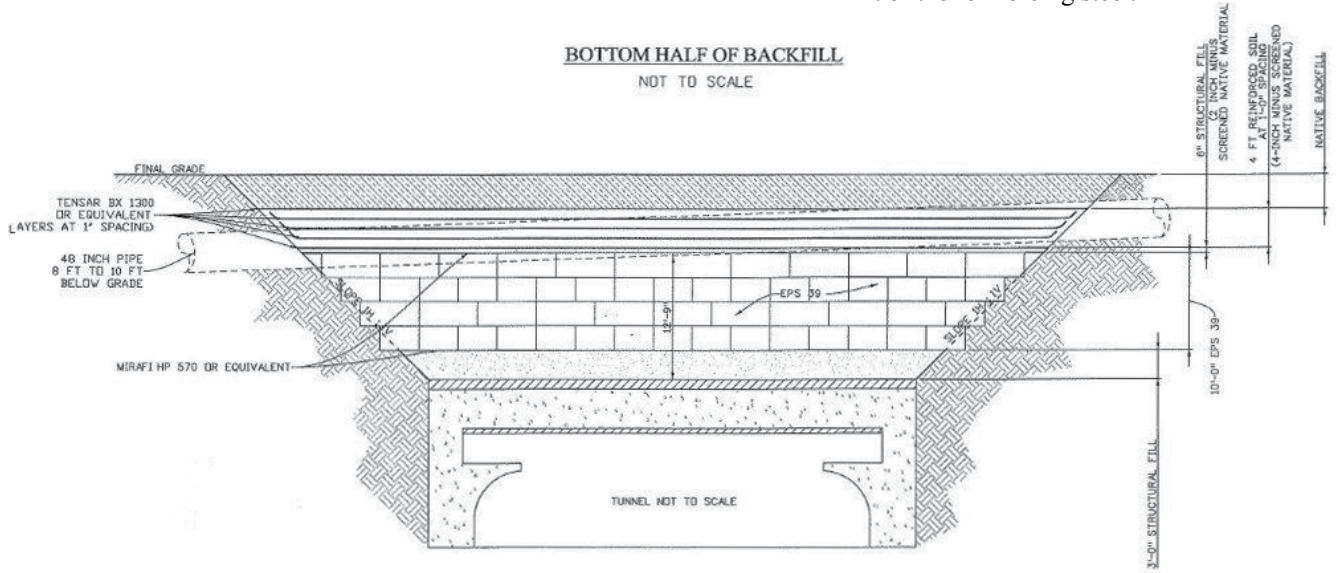
By Warren Harrison

During a Federal Highway Administration annual safety inspection in March 2007, a crack was found in the flat roof portion of the cut and cover section of the Hanging Lake Tunnels along Interstate 70 in Glenwood Springs, CO. The crack—an end shear failure—was discovered in the roof section of the eastbound tunnel only. The total displacement was 2 in. (50 mm) and moving.

The apparent cause of the failure was a rock fall in January 2002 that overstressed the open cut portion of the tunnel, adding 35 ft (10.6 m) of surcharge on top of the existing fill over the tunnel. The eastbound tunnel was immediately shut down after the crack was discovered, and the cracked roof section was temporarily supported with steel columns and heavy steel crossbeams to stop the failure. The roof displacement was monitored and stabilized by the steel sets. The total design, stabilization, excavation, and repair time was 6 months, with the eastbound tunnel reopening in November 2007.

Crack in roof

Dana Christensen, a Colorado Department of Engineering regional engineer, designed the repair. First, the excess rock and soil and the original backfill would be removed. The open cut tunnel portion was not accessible by road but was adjacent to the mainline Union Pacific Railroad track through Glenwood Canyon, making the removal process difficult. Concrete Works of Colorado, the excavation and support contractor, had to bring all equipment in by rail and use railcars to remove all of the material. The removal took several weeks, as there was limited availability of gondola cars to move the debris out due to the railroad's mainline schedules. With the removal of the rock and soil, the crack in the roof closed, as the loading did not exceed the plastic limit of the reinforcing steel.



Tunnel section showing final backfill with expanded polystyrene fill to reduce load

The design fix to the existing 4 x 40 x 105 ft (1.2 x 12 x 32 m) slab included drilling and placing 980 vertical No. 7 (No. 22) hook bars through the slab connecting an upper and lower mat of No. 10 (No. 32) reinforcing bar. The lower mat was encased with overhead shotcrete 6 in. (150 mm) thick and a top slab 18 in. (450 mm) thick poured in place. The overhead shotcrete was shot with no accelerator and encased the No. 10 (No. 32) bars. For convenience and splicing needs, the No. 7 (No. 22) bar was Grade 75 Dywidag threadbar.

The mixture was supplied and delivered by Casey Concrete from Carbondale, CO, with the materials in the design shown in Tables 1 through 4.

The mixture included fly ash to mitigate alkali-silica reactions.

The surface was prepared with sandblasting to a rough surface to aid in the bonding of the shotcrete to the bottom of the existing roof. After sandblasting, the roof was power-washed to predampen and clean the surface.

Table 1: Concrete Mixture Materials

Material	Source
Cement	Holcim Type I/II MA
Fly ash	San Juan Class F
Silica fume	Rheomac SF100
Fine aggregate	Mountain Aggregates, Casey Concrete
Coarse aggregate	Mountain Aggregates, Casey Concrete
Admixtures	BASF Rheobuild 1000, Micro Air, Delvo, Polyheed 997

Table 3: Physical Properties of Concrete

Property	Results
Unit weight of mixed concrete (ASTM C138), lb/ft^3 (g/cm^3)	136.0 (2.18)
Slump (ASTM C143), in. (mm)	3 (76)
Air content (ASTM C231, pressure method), %	7.20
Water-cementitious material ratio (*w/cm*)	0.44
Temperature (ASTM C1064), °F (°C)	72 (22)
Relative yield, yd^3 (m^3)	1.02 (0.78)

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The concrete was pumped with a Reed 4050 pump using a slump of 1 to 2 in. (25 to 50 mm) to aid in the attachment to the roof.

The final backfill over the tunnel included a thick layer of expanded geo foam to reduce the dead loading for the beam.

Table 2: Mixture Proportions per 1.01 yd^3 (0.77 m^3)

Material	Quantity
Cement, lb (kg)	660 (299)
Fly ash, lb (kg)	60 (27)
Silica fume, lb (kg)	60 (27)
WRA, oz (L)	94 (2.8)
Polyheed, oz (L)	36 (1.1)
AEA (micro air)	As needed
Retarder, oz (L)	30 (0.9)
Fine aggregate, lb (kg)	2040 (925)
Coarse aggregate, lb (kg)	560 (254)
Water, lb (kg)	341 (154)

Table 4: Compressive Strengths in psi (MPa)

7 days	28 days
4700 (32.4)	7520 (51.8)
4810 (33.2)	7680 (53)
4750 (32.8)	7740 (53.4)
Average	
4750 (32.8)	7650 (52.7)