Soudan Mine Shaft Rehabilitation

By Shane McFadden

The Soudan Mine is a historic taconite and iron ore mine in Northeastern Minnesota. First built in 1882, the Soudan Mine was one of Minnesota's only and deepest underground mines. Mining continued at the facility until the US Steel Corporation closed the facility in 1962, when production became too costly to sustain the operation. Over 80 years of mining production, more than 50 miles (80 km) of underground drifts, adits, levels, and raises were constructed, with the deepest being Level 27 at 2341 ft (714 m) below the surface—689 ft (210 m) below sea level. The mine was donated to the state of Minnesota in 1965 and is now operated as a state park by the Minnesota Department of Natural Resources (MnDNR). In the early 2000s, the National Science Foundation funded the construction of a major research laboratory on Level 27 to conduct physics and other scientific experiments. With the addition of the lab facility, the site serves the dual purpose of public recreation and education along with the advancement of cutting-edge science.

Access to the mine is through the main shaft and hoist system (Shaft 8). The hoist system is a dual-cage assembly, meaning that there are two cages attached to the hoist cables at all times. As one cage is lowered into the shaft, the other cage is concurrently raised. Along with personnel, equipment, and material conveyance, the shaft is the main conduit for all of the utilities to the underground portions of the mine, including the supply of air, power, and water, and the removal of groundwater. The shaft is split into three bays: two cage bays and one utility chase bay (refer to Fig. 1).

When the mine was first developed, modern drilling and mining techniques did not exist, making blasting rock very difficult and labor-intensive. Therefore, it was desirable to have the shaft closely follow the ore body to minimize the need to construct drift tunnels. In the case of the Soudan Mine, the shaft follows the edge of the main ore body, which lies at a steep angle (78 degrees) (refer to Fig. 2). Therefore, the shaft cages are hoisted vertically but are also supported horizontally by rails installed off the footwall of the shaft. The rails ride on structural steel sets that are spaced approximately every 4 ft (1.2 m) along the shaft. For the cages to ride smoothly along the length of the 0.44 mile (0.71 km) deep shaft, the rails and the corresponding supporting steel sets needed to be properly aligned. To accomplish this, the sets were supported against the irregular shaft walls with rough timbers harvested from the surrounding forests (refer to Fig. 1, 3, and 4). Approximately every 300 vertical ft (90 m) in the shaft, a concrete collar was placed tight to the rock to provide additional structural support to the shaft system.

In March of 2011, the supporting timbers of the shaft caught fire approximately 100 ft (30 m) above Level 27. This fire consumed the shaft and caused extensive damage from Level 27 up the shaft approximately 350 ft (110 m), including the burning of the shaft support timbers, pump and water supply lines, communications, power supply, warping of many of the structural steel supports, and destabilized portions of the surrounding shaft geology.

The MnDNR chose to execute the repairs to the shaft on an emergency fast-track design-build contract and selected the team of Engineering & Construction Innovations, Inc. (ECI); Engineering Partners International, LLC (EPI); and CNA Consulting Engineers, LLC (CNA). After defining the lower and upper limits of the damage to the shaft, the team's first task was to temporarily stabilize the shaft, re-establish the shaft utilities, and assess specific damage to the steel structure and the impact to the shaft geology. At that point, the repair options were evaluated. The following performance criteria were established:

- All shaft structural steel support timber materials needed to be removed;
- The shaft structural steel support structure needed to be positively braced to the rock;
- The rock surface needed to be stabilized; and
- The shaft needed to be protected from future rock falls or spalls.

Many repair methods were evaluated that met the design criteria. After thorough evaluation of the repair method options, the team determined

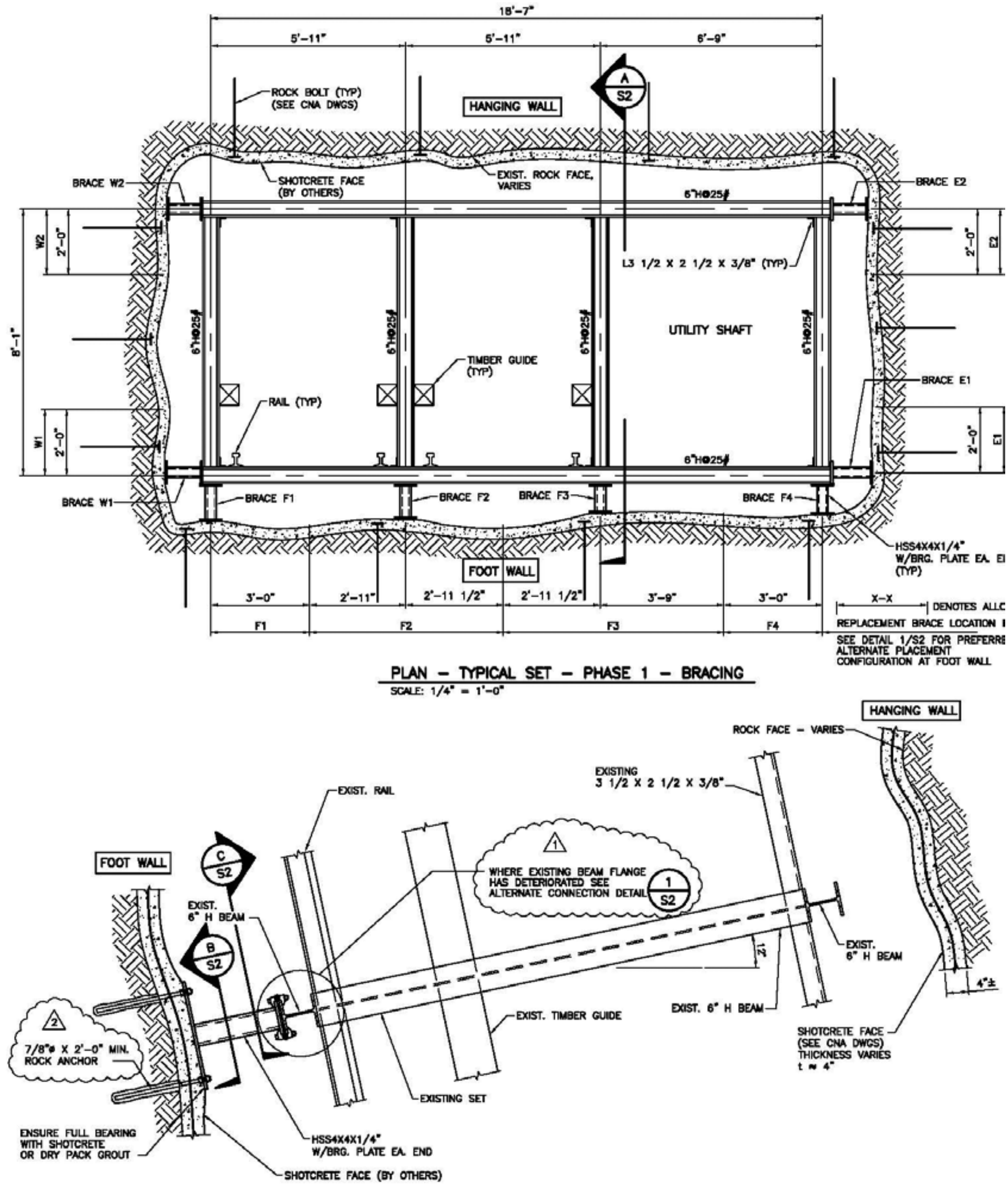


Fig. 1: Plan and profile section of the shaft repair (Note: 1 in. = 25.4 mm; 1 ft = 0.328 m)

that an upgraded structural steel support system with a reinforced shotcrete shaft lining was the most time- and cost-effective option.

One challenge to placing shotcrete on this project was that dust had to be minimized due to the proximity of sensitive laboratory equipment. Conveyance of bulk prepackaged shotcrete material to the repair area was difficult because of the available sizes of the shaft cages, and establishing an underground mixing plant at the available levels was impossible without extensive mining. Because of the physical constraints underground, ECI selected to establish on-site batching operations at the surface and pump the shotcrete from the surface down the shaft approximately 2300 ft (700 m) to the placement areas. To pump the required distance, a high-slump, self-consolidating mixture was designed with accelerator introduced at the nozzle. The product was to be pumped through a 2 in. (51 mm) line. A surface and procedure test was conducted, including full-mixture testing and the production of test panels. Once the shotcrete mixture and placement techniques were worked out, 2 in. (51 mm) slickline was installed in the shaft to the work area.

After the shaft and steel support structure was temporarily stabilized, the final repair was executed in stages from the upper limit of the damage to Level 27. The average stage length was 8 to 10 ft (2.4 to 3 m) and included removing the steel sheeting between the support sets,

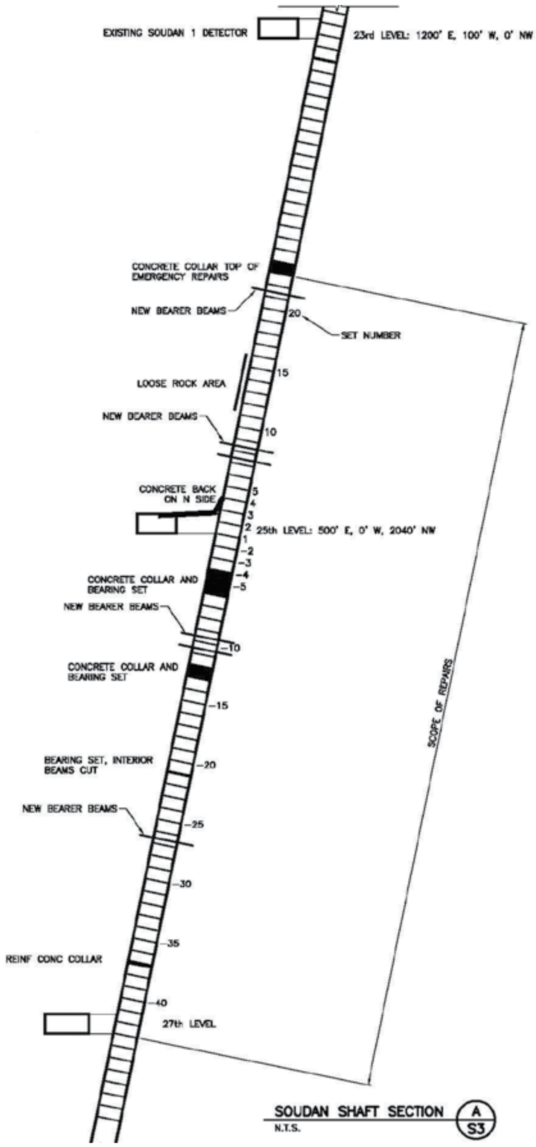


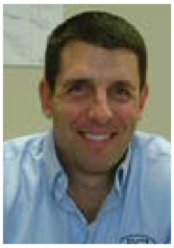
Fig. 2: Elevation view of the shaft repair area

removing all support timbers and loose or delaminated rock, installing new steel support columns, installing rock-bolts and reinforcing bar, and applying a minimum of 4 in. (102 mm) of shotcrete. Executing the work in this procedure ensured that personnel were always working under a safe, stabilized, and shielded environment. Shotcreting operations commenced in September 2011 and were completed in February 2012; the entire project was completed in May 2012. Approximately 500 yd^3 (280 m^3) of shotcrete was placed on this project.

This project was very difficult and risky for many reasons, including working at height, risk of falling objects, confined space, limited working room, obstructed access, and restrictive physical parameters. Shotcreting with the unique mixture design and engineered delivery system enabled the project team to deliver the project in a timely and cost-effective manner.

Fig. 3: Application of shotcrete on shaft wall

Fig. 4: Bottom of shaft



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