

FLANGED DEEP CORRUGATED VERTICAL SHAFT LINERS¹

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Vertical shafts are used for ventilation, access for equipment/personnel, or storm-water transmission to underground cavities. Larger diameter vertical shafts are traditionally lined using either concrete or flat steel forms. This paper introduces flanged deep corrugated plate (FDCP) as an economical vertical shaft liner.

For safety and accessibility reasons, shaft liners typically require installation be conducted from only one side of the liner. Shallow corrugated steel liner plates, which enables one side assembly, has been used for decades. However, shallow corrugated liner plate's strength has limited their use to smaller (less than 6 m) diameters. FDCP, commonly referred to as The Edge, was first introduced to the marketplace in 2012 and is five times stronger and nine times stiffer than traditional steel liner plate. FDCP is available in two-flange and four-flange configurations and is best suited for applications:

1. required to resist ground/hydrostatic pressures or ground movements greater than the capacity of shallow corrugated liner plate;
2. needing to resist unbalanced loads;
3. where greater flowable fill pour heights are desired;
4. with diameters > 6 m.

FDCP is designed to the same structural limit states as traditional overlap plates with the additional consideration of shear load at bolted connections. AASHTO LRFD Section 12.13 may be used as a guideline when determining loads and structural limit states for vertical shaft liners.

FDCP is well suited for vertical shaft liners. Vertical shafts with diameters > 6 m and depths < 40 m are generally more economical and faster to construct when lined with FDCP. Product and construction innovations are required to increase advancement rate and shaft depth for which FDCP compares favourably to traditional concrete liner.

Key words: Vertical Shaft Liner, Raise Bore, Flanged Deep Corrugated Plate, The Edge

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1. INTRODUCTION

Vertical shafts are commonly used for ventilation, access for equipment and personnel, or transmission of stormwater to underground cavities. ‘Shafts are the doorways to the underground, serving as the location at which all material enters and exits. They vary in size and depth, and their design and construction are key to the successful completion of any tunneling project.’ (Glenn M Boyce, 2016). Shafts are often lined to stabilize in-situ materials and prevent shaft failure and/or fall hazards. Vertical shafts are commonly found in urban infrastructure and underground mines.

The paper will benefit practitioners by introducing FDCP for use as a vertical shaft liners. This paper introduces FDCP shaft liner:

1. Suitable applications;
2. Configurations;
3. Design criteria;
4. Construction methods;
5. Comparisons to alternative vertical shaft liners.

2. FLANGED DEEP CORRUGATED PLATE APPLICATIONS

For safety and accessibility reasons, shaft liners typically require installation be conducted from one side of the liner. Shallow corrugated steel liner plates, which typically have a corrugation depth less than 50 mm, have been used for decades. However, the strength of traditional shallow corrugated liner plates has limited their use to smaller (less than 6 m) diameters. Flanged deep corrugated plate (FDCP), commonly referred to as The Edge, was first introduced to the marketplace in 2012 (Williams, Newhook, & MacKinnon, 2012), and is 140 mm deep. FDCP is approximately nine times stiffer and five times stronger than traditional steel liner plate. FDCP’s larger stiffness provides a greater resistance to unbalanced loads such as live load or flowable fill forces incurred during placement material between the liner and shaft wall. This is beneficial when large, unbalanced voids between the liner and shaft wall exist. FDCP’s larger yield strength and cross-sectional area provides greater resistance to ground/hydrostatic pressures and ground movement. As a result, FDCP is viable for shaft liners:

1. required to resist ground/hydrostatic pressures or ground movements greater than the capacity of shallow corrugated liner plate;
2. where greater flowable fill pour heights are desired and/or where large cavities between the liner and shaft wall exist;
3. with diameters > 6 m.

3. FLANGED DEEP CORRUGATED PLATE CONFIGURATIONS

FDCP differs from traditional deep corrugated plate in that FDCP permits assembly from one side of the structure whereas traditional overlap deep corrugated plate requires access on each side of the plate. FDCP is produced in two flange circumferential, two flange longitudinal (Figure 1), or four flange circumferential and longitudinal seam plate (**Błąd! Nie można odnaleźć źródła odwołania.**). Two FDCP longitudinal is typically used for shafts less than 6 m in diameter as this configuration eliminates the protrusion of circumferential flanges into the shaft, maximizing end area and work space. Additionally, two longitudinal FDCP is more cost-effective for diameters less than 6 m due to a premium cost associated with fabricating a circumferential flange on smaller diameters. Four FDCP is normally used for shafts with diameters greater than 6 m. FDCP material and fabrication criteria are outlined in ASTM A761-16 and CAN/CSA G401-14.



Figure 1. 4 Flange (left) and 2 Flange Deep Corrugated Plate (right)

4. FDCP SHAFT LINER DESIGN

AASHTO LRFD Section 12.13 (Transportation, 2016) outlines a design procedure for traditional tunnel liner plate. While the design method is intended for horizontal tunnels, design requirements outlined in AASHTO are relevant for vertical shaft liners.

Loads: AASHTO has design provisions for earth load, live load and grouting pressure. Earth loads applied to the liner are a function of the site's ground conditions and depth. Soils with swelling potential will apply significantly larger earth pressures compared to sand/gravel or even hard/intact rock. Live load is typically negligible for vertical shaft liners. Grout is usually placed in a non-pressurized fashion, and the applied grout pressure is commonly calculated based on static head. Additional project considerations such as additional load-

ing from hydrostatic pressure, ground movement, equipment supported by the liner, or seismic conditions should be considered. It is noted that FDCP's deeper corrugation profile is better capable of withstanding unbalanced loads such as slough-ins, unbalanced fluid infill placement, and concentrated loads.

Structural Limit States: FDCP is designed considering the same structural limit states as traditional overlap deep corrugated plate. Bolt shear in the connection is also checked. However, the flange connection outlined in ASTM A761 has a very high shear resistance and shear failure at the flange connection is not expected to be a governing limit state. AASHTO has design provisions for wall area (yielding under axial loads), buckling, seam strength, and structure stiffness. It is recommended these provisions be considered and reference be made to AASHTO Section 12.8, which contains equations for wall area, buckling and seam strength structural limit states for deep corrugated plate. Shaft liners should be designed for moments. Applied moments should be determined considering FDCP's flexibility and soil-liner interaction.

Curb rings, which are placed at the underside of the shaft liner during construction and contain in-fill placed between the shaft liner and wall, are designed to resist static pressure from the in-fill. An example of a curb-ring is illustrated in Figure 7.

5. CONSTRUCTION

Vertical shafts are constructed using one of two methods: top down, and bottom up.

Top-down construction utilizes either conventional drill and blast, or the raise bore drill method. A typical raise bore drill technique is outlined in Figure 2 and requires access to the bottom of the shaft.

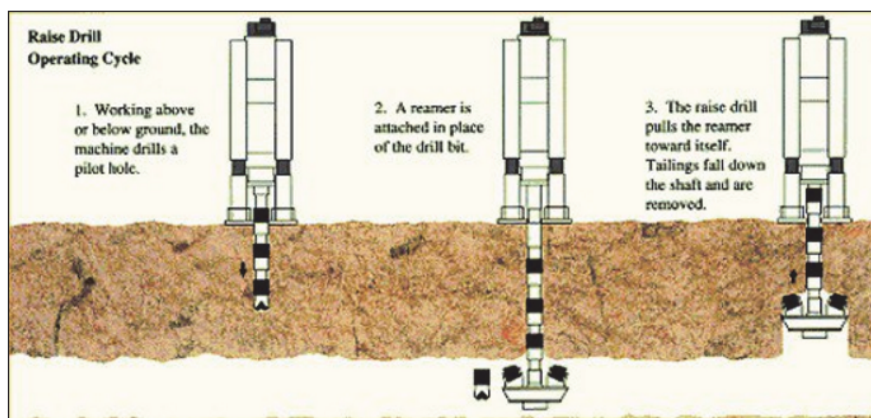


Figure 2. Raise Bore Construction (Priyadarshi , Fenrick, & Caldwell, 2017)

Bottom-up, or raise bore construction, utilizes a much smaller operation that drills the shaft from inside the tunnel or drift, up to the overburden. This method utilizes a small footprint on the surface, and the broken rock is hauled away with load-haul-dump (LHD) equipment. Both top down and bottom up construction can achieve larger diameter using conventional drill and blast practise from the top down if required (Shutters & Morgan, 2017).

The shaft liner design is expected to be similar for both top down and bottom up construction. If shafts are pre-assembled and rasied or lowered into place, a design check is required to ensure the structure is assembled section is capable of resisting its own self weight.

5.1. Case study: vertical shaft liner construction

The “Edge” four flange FDCP liner was used as a type of grout form and final lining for a ventilation raise approximately 6 m in diameter, and 33 m in depth. The initial pilot raise was constructed with a raise climber from the level below surface, at an approximate diameter of 2.5 m. The shaft liner passed through five different zones of soil/rock: pumice, clay, colluvium, argillized andensite and compentent andensite.

Due to the different types of soil/rock formations, traditional concrete slip lining could not be used, as the concrete would not cure properly due to water infiltration and poor curing conditions. During the design phase of the project, the FDCP liner thickness was varied based on loading to maximize the final ground support, and to maintain a cost effective liner solution.

The structural liner was installed starting at the surface and progressed downward. Miners assembled two complete rings of structural liner, forming a sub-collar, which was then placed directly over the pilot raise opening. From there the sub-collar was levelled using a concrete pad, tied in with a series of rebar to form the overall collar. This gave the rest of the shaft its alignment for advancement.



Figure 3. Sub-collar Construction

Once the sub-collar was completed, miners installed four more complete rings on the top of the sub-collar, and backfilled the area, returning the site to its original grade. A crane and man basket was then brought in to assist with the rest of construction.



Figure 4. Finished sub-collar

Each FDCP liner ring consisted of five plates. Every third ring installed had two grout spigots per plate, as a grout height of 1.5 m was the determined pour height for each cycle.

Once the crane was in place, miners were lowered into the lined portion of the shaft on a platform that closed off the original pilot hole, to drill and blast the opening to the final diameter. After each blast the miners were lowered back into the shaft, where rock bolts and screen were installed, followed by shotcrete placed against the shaft wall. Each FDCP plate was lowered into the shaft and raised into position for bolting to the shaft liner.



Figure 5. Shaft platform



Figure 6. Installing plate

After three rings were assembled, miners would install scribing pins into the shaft wall. The ends of the scribing pins were supported by angle iron attached to the underside of the FDCP liner. Wood formwork was then suspended from the circumferential flange to act as a type of curb ring, or form work to cap off the bottom of the liner (Figure 7. Formwork). Grout was then placed in the closed off cavity. After each grout pour had set, formwork and pins were removed and the cycle repeated itself until they completed the shaft. Once completed, a rail and climber were installed and the shaft was used as a service/vent raise.



Figure 7. Formwork



Figure 8. Finished shaft liner

6. COMPARING FDCP TO TRADITIONAL CONCRETE LINERS

A construction time and installation cost comparison of a 6 m diameter vertical shaft lined with FDCP (using the construction procedure outlined in Section 5.1) and a 0.3 m thick traditional concrete liner was completed. The study was based on the following key parameters:

- Construction costs are based on Ontario, Canada;
- A construction crew of five;
- Drilling and excavation times are independent of liner type;
- Grout lift heights:
 - Soft soil: 1.6 for for FDCP and concrete,
 - Hard soil: 2.3 m for FDCP, 5 m for concrete.

Grout lift heights for FDCP were assumed to be less than conventional liners based on the practical experience at that time of the study. It has since been realized FDCP is capable of supporting grout lift heights up to 5 m. The study concluded:

- FDCP shafts constructed as outlined in 5.1 have a lower initial capital cost and accelerated construction as FDCP may be used as a form during construction of the sub-collar;
- FDCP shafts constructed as outlined in 5.1 have a slightly higher cycle time than traditional concrete liner;
- Grout pour height has a significant influence on cycle time;
- FDCP shafts constructed as outlined in 5.1 are faster to install and more economical for shallower shafts;
- Conventional concrete liners are more economical for deep shaft liners.

The author's practical experience is in typical conditions, FDCP compares favourably to concrete when shaft diameter is > 6 m and shaft depth is < 40 m. This is due to FDCP's accelerated sub-collar construction, and ease of shaft alignment resulting in lower setup costs. It is important to note the 40 m number is subjective to several factors such as loading condition, site location, labour cost, grout pour height, and construction innovations. The study identified a need to further innovate FDCP construction practices such as increasing grout pour height or developing a more time-effective curb ring. These innovations would reduce cycle time and increase the depth for which FDCP has lower construction cost and construction time compared to traditional concrete liner.

7. CONCLUSIONS

FDCP brings to the market a corrugated steel liner which can be assembled from one side and is significantly stiffer and stronger than traditional shallow corrugated liner plate. FDCP is well suited for urban-transportation vertical shaft liners and is often a more economical liner than concrete when shaft depth is < 40 m and diameter is > 6 m. Product and construction innovations are required to increase advancement rate and shaft depth for which FDCP has lower construction cost and construction time than traditional concrete liner.

LITERATURE

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