Sacramento UNWI Sections 1 and 2 Project: Special Tunnel Construction with Plastic-Lined PCC Segments

Jeremy Theys
Traylor-Shea Joint Venture, Sacramento, California

Michael Lewis, Greg Watson
The Robbins Company, Solon, Ohio

ABSTRACT: The UNWI project was undertaken by Traylor Shea, a Joint Venture for the Sacramento Regional County Sanitation District. It features the first use of plastic-lined concrete segments in North America combined with rapid segment delivery and installation, tight curve radii, tunnel conveyor mucking and abbreviated startup. This inner lining prevents deterioration of the segments by corrosive sewer gases. Once the segments are in place, the joints between segments are heat-sealed together to form a complete liner. Unique solutions were devised to protect the plastic lining without sacrificing the high performance objectives of the system or the safety of the crew.

INTRODUCTION

Plastic (PVC) lined segments have much to offer as long as they can be applied efficiently and effectively. They eliminate the corrosive effects of sewer gases collecting in the crown of the tunnel once in service, reducing the need to periodically drain and flush the interceptor tunnel. Due to their special characteristics, however, new techniques in handling, placement and protection after placement are required. In addition, heat welding of the lining seams within the TBM and backup provides early access for the work, ensuring it can be completed before being blocked by tunnel services.

This paper will outline the experience of adapting this type of segment to present TBM technology, and the techniques that had to be developed to address this challenge. The segments were used on the Upper Northwest Interceptor, Sections 1 & 2 Tunnel project in Sacramento, California, which was the first application of this lining in the U.S. This project was undertaken by the Traylor Shea Joint Venture for the Sacramento Regional County Sanitation District, designed by URS and managed by Hatch Mott McDonald. The geology was clay and running sand. In addition to the 60 inch wide PVC lined segments, the tunnel alignment included 10000-ft radius horizontal curves. A 4.2 m (13.9 ft) Robbins single shield EPB TBM backup and continuous conveyor were selected to excavate the tunnel. The TBM featured tungsten carbide knife edge bits and triple-row disc cutters, as well as active articulation to assist in steering.

PLASTIC (PVC) LINED SEGMENTS

The PVC lining was embedded into the concrete I.D. of the segments and once the segments were installed the liner was fully heat welded to ensure a continuous “pinhole free” liner. The Traylor-Shea Joint Venture designed the precast concrete segments to accommodate flaps overhanging the edge of the segments. These flaps were incorporated to facilitate welding one segment to the next and to minimize the PVC welding materials and labor needed. Once the segments were erected and grouted in place, the joints or flap edges were joined using a separate welding strip. The welding strips were applied manually using electric heat guns (see Figures 1–2). The strips melted with the application of heat and the molten material created the bond.

The flaps could have been placed on either the radial or circumferential joints or both. Which edges the flaps are placed on is dependent on whether or not the segments are universal, as well as the desired build orientation. For the UNWI project, the flaps were used initially on the radial joints and then eventually also used to the circumferential joint. The flaps were designed to provide the same width as the primary joint strip overlap, so that no loss in sealing capacity was recognized. The size and location of the flaps had also to be considered in the delivery sequence, storage and handling of the segments. The

Figure 1. PVC lined segments with flaps

Figure 2. Sealed radial and circumferential joints

144" segment ID was relatively small compared to the 60" segment width, which made transport of the segments through the backup already challenging. The overhanging flap on the circumferential edge of the segments added to their width, making transport much more difficult. The flaps also had to be considered throughout the segment delivery and handling processes in the shafts and tunnel. The flaps on the radial joints were less of a problem since they projected fore and aft at that stage while passing through the backup. Alignment dowels at the circumferential joints would also have added to the segment width if they had been inserted before being brought into the tunnel. Therefore, all segment dowels were shipped to the heading and installed in the segment build area immediately before erection at the face.

To maximize efficiency and to satisfy the tight contract schedule, a certain minimum portion of the welding process had to be completed in front of (or somewhere along) the backup. This was in areas that would later be blocked by utilities and services installed to the tunnel wall near the end of the backup. These areas included the continuous conveyor, fan-line, high voltage cable, compressed air, water, dewater, grout and accelerator lines and track.

Workstations for welding were located in proximity to these locations and provision for this had to be considered in the backup design. Well-designed work stations were important because the welding was a continuous process throughout tunneling excavation. Furthermore, the welding process demanded appropriate lighting and power takeoffs for the 220V weld guns.

To permit welding of the PVC joints at all locations, three distinct work areas were provided on the TBM backup gantries. To access the lower portions below springline, the PVC welders had to weld the joints in the area between the segment feeder and the front of Deck #1. This area was often congested as it was the travelway for the precast concrete segments from the TBM backup to the segment feeder.

A dedicated workdeck was also installed in the same area of the TBM, immediately behind the discharge chute of the screw conveyor. This deck, along with numerous welding gun power takeoffs, proper lighting and storage areas to support the welding operation, was used to weld all the PVC joints in the upper portion of the tunnel. It was critical to the process as it allowed the only access to the crown before it was blocked by installation of the mainline conveyor. As it was the only possible location, the welding process had to share the work deck area with the fresh air duct. The duct was made flexible so that it could be pushed from side to side to access the entire crown. In this way, the 15' long deck provided sufficient access to this area of the tunnel to allow efficient welding of the joints as the tunnel advanced (see Figure 3).

The last work area in the process allowed welding of the PVC joints at the approximate springline locations of the tunnel on both sides. Conveniently, the two backup decks designed for installation of the mainline conveyor gear provided adequate access to both springline locations for PVC welding. Adequate lighting and power takeoffs completed the preparations to allow welding in this location.

As the mining progressed, Traylor Shea JV made numerous improvements to the welding process that maximized efficiency, including staging various laborers at each workstation during mining and staging materials in critical areas within easy

Figure 3. Work area with fresh air duct

Figure 4. Heat welding of seams

reach. The Resident Engineer's tunnel inspection team provided oversight of the process as well as proof testing of the welds using rounded-edge putty knives. Traylor Shea provided testing checks of the welds using Tinker Rasor spark testing devices. Final testing and repairs remained to be completed at the time of this writing (see Figure 4).

Traylor Shea JV scheduled the PVC welding to proceed as the mining progressed and planned to achieve at least 50% of the joint welding during the tunnel drive. To make up for lost time in the TBM manufacture/delivery phase, TSJV hired additional labor (certified PVC welders) to increase the production and makeup time on the schedule, eliminating a lot of the welding that was scheduled to take place after the excavation phase was complete. At the 85% excavation point, TSJV had achieved much higher completion percentages than scheduled. Average PVC welding rates were roughly one linear foot of weld per minute.

TIMING

Traylor Shea was focused on minimizing construction time by maximizing the rate of advance. As such, rapid segment delivery and placement were key factors.

Based on the long tunnel length and use of conveyor belt to remove the tunnel spoils during the excavation, the JV decided it would be advantageous to design the TBM to handle two rings worth of segments on each load. This design resulted in the need to deliver a train full of segments only once every hour, reducing the number of trains in the tunnel and eliminating the need for a passing track. However, two rings worth of segments would cause the segment handling area and trolley to become quite long, making a very long trip from the furthest segment stack to the segment erector. Such a trolley would have to travel so fast to supply the erector during the build that it would not be feasible or prudent.

The remedy was to implement a system which included segment lifters and a segment feeder. The segment lifters allowed the two rings worth of segments to be offloaded and stored on the backup in an instant, allowing the trains to immediately return to pick up another load. The feeder stored enough rings immediately behind the erector to keep it supplied, even though the erector used segments faster than the trolley could bring them. The feeder became depleted at the end of each build but there was enough time to refill it during the push. (see Figure 5)

The time study, shown in Figure 6, was used to determine the speed and capacity parameters for the segment lifters, hoist and feeder. The cycle time was designed to allow both the advance of the TBM and erection of the 6-piece segmental liner in an approximately 30 minute timeframe, which was composed of 15 minutes of ring building and 15 minutes of mining. This cycle resulted in a segment feeder capacity of three segments. To ensure an uninterrupted supply of segments, four sets of segment lifters were included in the backup design to collectively handle 2 complete rings.

THE FEEDER

Ordinarily, segment feeders run on wheels. Feeders need to be low profile enough so that they can insert the segment below the erector pickup. This limits the possible diameter of the wheels. Given the small diameter and low contact pressure allowed for the wheels, many wheels would have been required. Ensuring that all of these wheels would have equal loading, especially in a tight curve, seemed impractical so the decision was made to suspend the feeder from beams running between the TBM and backup. These beams also served to tow the backup and support walkways along the feeder leading to the TBM.

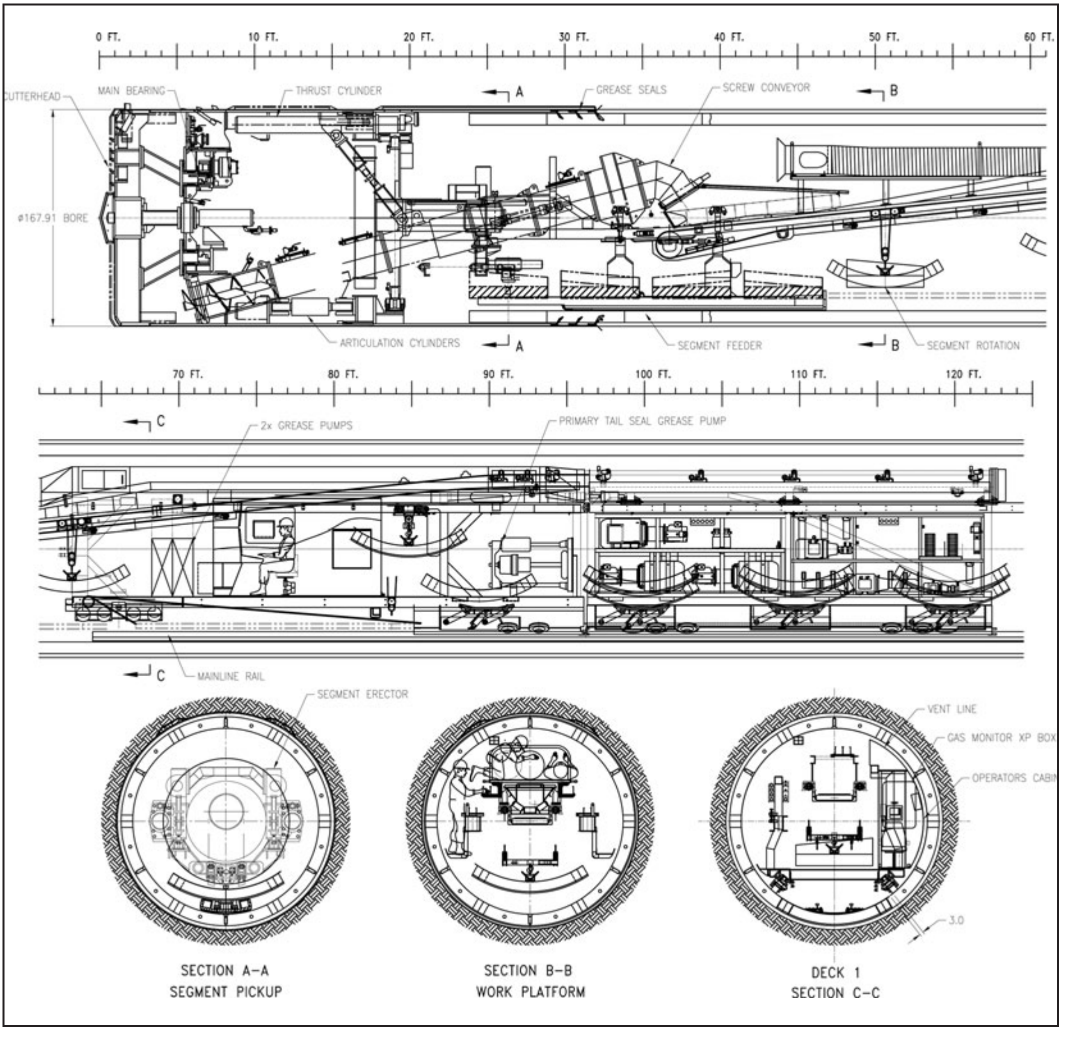

Figure 5. TBM general assembly

Because the feeder was much closer to the TBM, most of the feeder load was transferred there. The towing frame of the TBM had to be heavily reinforced to accept this load. This setup was difficult because there was only so much clear space inside the erector and most of this was taken up by the screw conveyor and the many hoses and cables. One consequence of the design was that access into the shield was more limited than it would have otherwise been.

TSJV's design specifications called for a 750 ft horizontal and 1,500 ft vertical curve capability. Clearance both inside and outside of the feeder suspension system had to accommodate these relatively sharp curves as well as the PVC flap on the segment. To provide the maximum clearance for the extended segment with the erector pickup head, the feeder was suspended on four hydraulic cylinders. These lifted the feeder off of the lining for the push but lowered it again prior to feeder extension. This design prevented the suspension system from being damaged in the event that the erector pickup was accidentally extended instead of retracted when picking up the segments (see Figures 7–8).

ABBREVIATED STARTUP CONFIGURATION

The starting pit contained approximately 130 ft of useable length, meaning that the length of the TBM plus backup, at startup, could not exceed this

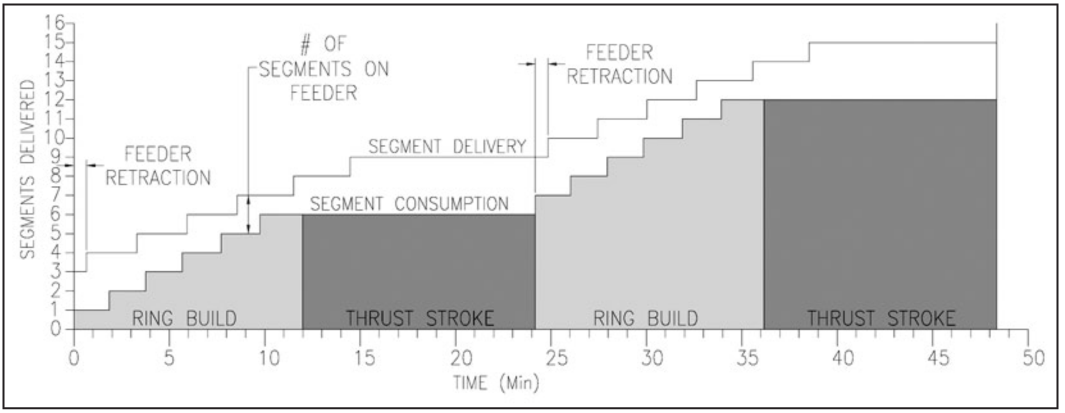

Figure 6. Segment building time diagram

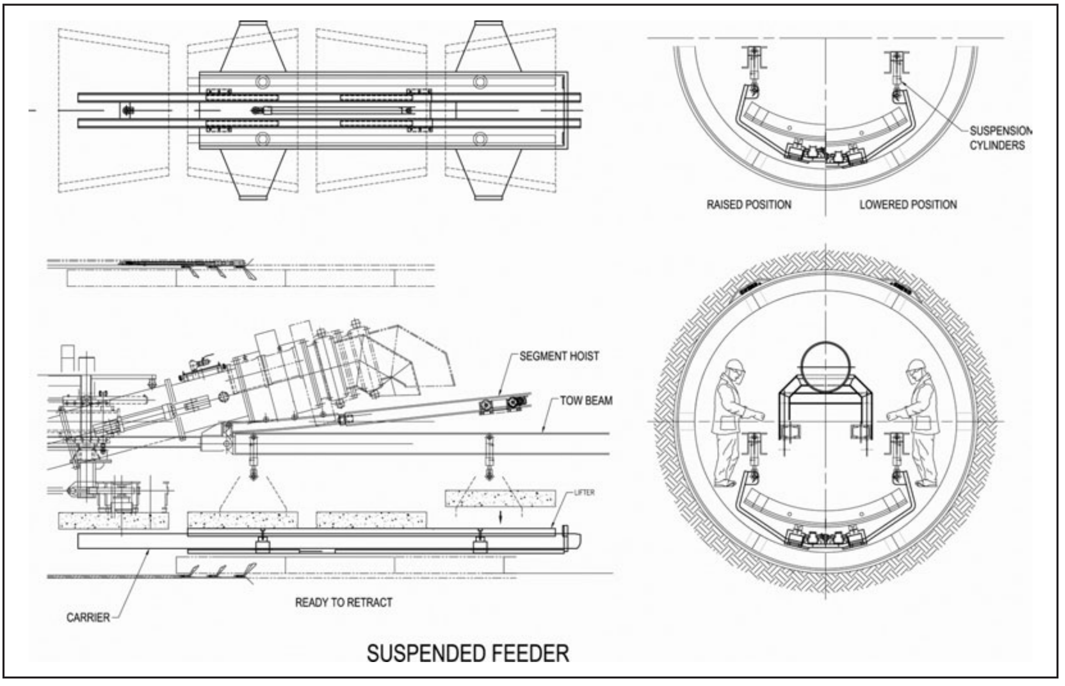

Figure 7. Segment feeder diagram

distance. This was initially expected to be sufficient for the bridge and three decks behind the TBM, as there was 25 ft between the TBM and deck 1. Four decks would contain all of the hydraulics but none of the electrical. However, the 25 ft space between TBM and backup was barely sufficient for a short feeder and the installation of half length rails (16.5 ft). Though beneficial for startup, this short arrangement would have been a handicap for the remainder of tunneling. The development of a started tunnel was not practical in the pressurized soil environment and so the most compact starting arrangement had to be devised while still preserving efficient segment storage as well as the ability to set full length (33 ft) rails (see Figure 9).

DECK 1 STRUCTURE

To minimize roll-back of liquefied spoil, the incline of the belt was limited to 6°. At this angle, to reach

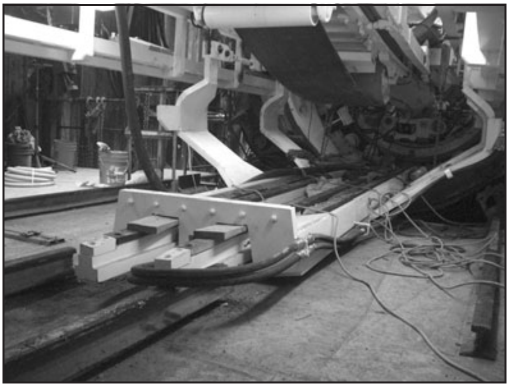

Figure 8. Installed segment feeder

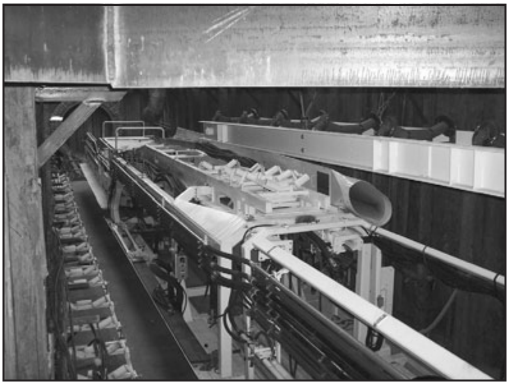

Figure 9. Abbreviated startup configuration

the elevation of the main run of the conveyor, the bridge needed to be 56 ft long. Given the compressed startup length, this put the rear support point of the bridge near the rear end of deck 1 and caused the bridge to run right through the deck. This meant that the movement of the bridge, due to curves, that normally occurs out in front of deck 1 now had to be accommodated within it. Due to the severity of the curve requirement, the amount of this movement was greater than normal. This movement meant that upper portion of the structure had to be open at the forward end to clear the bridge. The segment hoist, being an integral part of the bridge, also experienced significant lateral movement in a curve. Therefore, the structure had to be contoured to clear the already wide segment when carried along an offset path.

The 33 ft rail requirement, together with the short startup, meant that the rail setting activity would have to take place mostly within the length of deck 1. In order for this to occur, the forward portion of the bottom deck needed to be open. Having both the top and bottom of the deck open at the front would have been ideal from a functional point of view. It was, however found to be impractical from a structural point of view. With an open bottom the front wheels had to contact the tunnel walls at about 4:00 and 8:00. This created additional inward forces, which would have acted to collapse the C shaped deck. In the end a transverse brace was added to the bottom deck at the front. The brace made setting the rail more challenging but still practical. This brace was later lowered to make it less of an obstruction to foot traffic while still allowing rail installation (see Figures 10–11).

Figure 10. Track laying process

WHEELS IN CONTACT WITH PVC LINING

Since the rails were not in place ahead of deck 1, the front wheels had to run directly on the PVC tunnel lining. Due to the delicate nature of the PVC inner lining and its critical importance, great care had to be taken to prevent damage during installation, or by contact with the backup. Except for the bottom drainage, the PVC lining had to be 100% sealed so any damage had to be fully repaired. Ultimately, the lining was 100% spark tested so quality assurance of welding and prevention of damage was a must. Since some of the backup wheels rolled directly on the lining, the acceptable contact load had to be determined

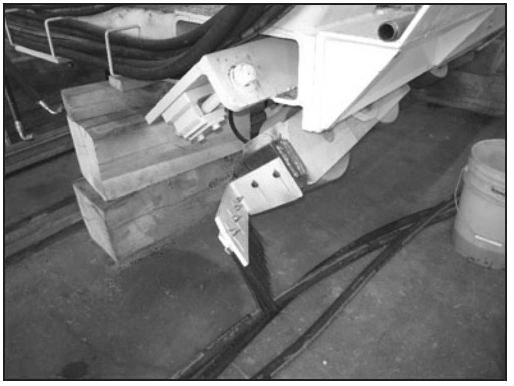

Figure 11. Elastomeric wheel assemblies with brushes and adjustable alignment

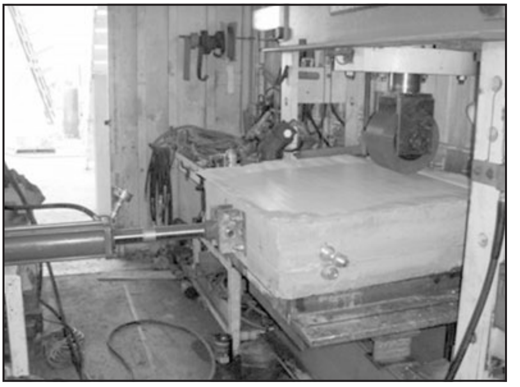

Figure 12. PVC liner testing

for the particular wheel type used. Traylor Shea JV performed loading testing of elastomeric wheels on the Ameron T-lock sheets to determine loading limits and prevent damage. The testing was carried out on site using 60 durometer urethane wheels left over from previous projects. The wheels were tested by pressing the wheel into the PVC sheet, which was then held for up to 24 hour increments using hydraulic cylinders to apply varying loading. The testing resulted in a contact pressure of 1,000 psi, or about 6,000 pounds of force per wheel. Once the critical loading pressure was determined, a series of tests were performed to determine any damage caused by movement of the wheels under the high pressures, namely rolling damage and damage caused by embedded grit from a dirty liner. Traylor Shea determined that the sideways loading on the wheel edges did not damage the PVC liner. However, dirt and debris on the PVC sheet caused very serious damage to the liner as the loaded wheel pressed the grit into the sheet. This caused enough damage to result in a failed spark test. Once this analysis was performed and the results realized, a cleaning system in front of the urethane gantry wheels was deemed to be necessary. TSJV recommended that brushes or air puffers be used to push any such material out of the path of the wheels. Brushes were ultimately supplied. Throughout the tunnel drive the brushes provided adequate cleaning capability to prevent debris from become embedded in the liner (see Figure 12).

The most direct way to protect the lining from the wheels is of course to reduce the load as much as possible. Typically, the front wheels of deck 1 are among the highest loaded wheel positions on the backup because they normally support the rear of the bridge conveyor, segment hoist, segment cars, TBM equipment and half the weight of the deck itself. In this case though, the largest portion of the load was contributed by the full segment feeder. As mentioned earlier, most of the load was supported by the TBM but the rest was supported at the front of deck 1.

The front half of the deck structure was another component of the load but this was already minimal due to the open bottom and top at the forward end. There was very little equipment mounted on the deck and therefore no ballast required either. Only two small grease pumps and the operator cab occupied most of the deck length, and they were not very heavy. The larger tail seal grease pump was located at the rear of the deck but sat directly over the rear wheels so it did not contribute to the front wheel load. Only one set of segment lifters was located on this deck at the rear, so only one segment car would reach that location. It carried 3 segments and weighed 7.5 tons. The car and the lifting mechanisms were located just ahead of the rear wheels and so didn't contribute significantly to the front wheel load.

The rear half of the bridge is normally supported at the front of deck 1 and so is typically a major component of its front wheel load. As noted above, however, due to the 6° maximum belt inclination the rear of this bridge rested near the rear of the deck. Given its minimum length, it would have ended directly over the rear wheels. The bridge, therefore would not have contributed to the front wheel load. Instead of simply allowing the bridge weight to remain neutral, however, the bridge weight was used to counteract the load on the front wheels. The counterbalancing was done by placing the support point as far behind the rear wheels as possible while still remaining on deck 1.

The monorail or segment hoist along with its cargo were supported by the bridge and so their weight also contributed to the force behind the rear wheels, thus acting to reduce the load on the front wheels.

Figure 13. Rear PVC welding station and continuous conveyor tailpiece

A downward force is created on the front wheels any time the towing connection at the front of deck 1 is located above the couplers pins between decks. The towing load on a backup can be quite significant particularly if the backup is long. The equipment on long backups is placed on only one side, therefore requiring ballast and bronze bearing wheels– as was the case in Sacramento. This load created a moment based on the vertical distance of the towing point above the deck couplers and was reacted by the front wheels. To remove the load, a hydraulic cylinder was placed at the top of the deck structure between decks 1 & 2. The cylinder passed half the towing load into the deck 2 upper structure where it could be counteracted by the weight of decks 2 and 3. To avoid complex pressure control, the cylinder was simply connected in parallel with the main tow cylinders. In this way, exactly half of the tow load was directed to the top of the structure and half to the bottom. This arrangement removed the moment and thus the vertical component of the wheel load.

Taken together, all the factors above resulted in a wheel load of approximately 2,000 lb per wheel—well below the acceptable load of 6,000 lb determined by testing.

Beyond minimizing the wheel load, bogies were designed to fully equalize the wheel loading. This meant that each two-wheel bogie was mounted on a center pivot. The two bogies were then mounted on a larger bogie which itself had a center pivot connecting it to the deck. In addition, the front wheel assemblies featured adjustable alignment to minimize skidding.

CONTINUOUS CONVEYOR

A crown-mounted tailpiece was selected for this project. This type of arrangement allows better use of the backup space. With side mounted conveyors, any deck space to the rear and on the same side as the conveyor is essentially useless. In a smaller tunnel, the opposite side of the backup will usually be occupied by a dedicated walkway. This arrangement is used because that space is already occupied by the erected conveyor. The typical solution is to put the tailpiece as far back as possible. This, however, makes for a long transfer conveyor and makes it more difficult to combine the transfer conveyor and continuous conveyor into a single belt.

Combining the two conveyors can be beneficial in that it allows at least one, and possibly two, transfer points to be eliminated. In small tunnels, the head room saved through the elimination of a transfer point can be very valuable. This was the arrangement used on the UNWI project. Due to space constraints, the segment hoist, bridge conveyor and continuous conveyor were integrated into a single unit. A consequence of the design was that the return pulley, just under the TBM discharge, was much larger than it would otherwise be. This cramped the space for bypassing the feeder with the segment but was still utilized successfully.

At the tailpiece, the vent ducts were run downward into deck structure below to allow unobstructed access to the tailpiece. This design also provided for better access to the PVC lining for welding.

SAFETY

The PVC liner sheets, when wet, were slippery and presented a slipping hazard. Though it was not practical to place walkways and scaffolds in every work area, it was nevertheless a priority in the design criteria. Designers found, however, that the problem could be easily avoided by performing a rough cleaning of the lining after segment installation. Complete cleaning of the joint was performed just before the welding was to take place. Even then, only the area local to the welding location was cleaned so that the remaining dust could provide a safe amount of traction for walking. To further address the slip hazard, the backup gantries were designed to ride on mainline tunnel rail. This design prevented the workers from the constant hazard of walking on the slippery PVC surface. It also prevented damage from the equipment and processes taking place along the TBM backup gear during normal mining operations.

Fire hazards were also of concern and therefore all consumables (greases and oils) used were fire resistant. Also, the conveyor system booster drives were outfitted with temperature sensors. The conveyor system was outfitted with many sensors which were tied into the global PLC control and monitoring network. These sensors included slip sensors, heat sensors, drive amp monitoring, etc. These sensors transmitted the status to the PLC network many times per second. Traylor Shea implemented many alarms monitored on the TBM operator and office monitoring screens in case any of the sensor readings approached levels that required corrective action. All of the sensors were tied to an automatic shut down in case dangerous levels or hazards were indicated.

In addition, before starting the mining operation, Traylor Shea performed rigorous fire testing on the PVC liner to determine the flammability hazard. The testing proved that the fire would not propagate through the PVC sheet.

CONCLUSION

The PVC lined segments used in the UNWI Sections 1&2 Tunnel Project, along with high performance expectations, tight curves and limited startup length, prompted many new considerations in design, implementation and operation. The solutions and techniques developed on this project have contributed toward what is fully anticipated to be the highly successful first application of PVC lined concrete segments in North America. The high advance rates achieved so far, placing the project well ahead of schedule, have demonstrated the viability of this technology going forward.