# FINAL DRAFT Geotechnical Design Memorandum #12

# Muck Handling, Storage, and Disposal in Confined Urban Areas – Rev A

GPC6, C-2012668-02, Task Order #39 Dallas CBD Second Light Rail Alignment (D2 Subway)

Final DRAFT

Dallas, TX
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**None.**

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# 1 EXECUTIVE SUMMARY

This technical memorandum provides the results of an analysis of the on-site handling and removal from the site of loose excavated material, muck or spoil, from the excavations. Muck handling requirements for the DART D2 program, as it relates to both Tunnel Boring Machine (TBM) and roadheader excavation are investigated for running tunnels, cross-passage, 1 mined station and two cut and cover station constructions. It is assumed that the station construction would implement mining by sequential excavation method (SEM). This technical memorandum describes options for the available site facilities and provides a typical site facilities diagram for the confined area at the West Portal. Potential site facility diagrams for the station caverns will be developed at a later stage, when potential mucking shaft locations are identified.

# 2 INTRODUCTION

This technical memorandum provides the results of a preliminary investigation into the muck handling requirements for the DART D2 program, as it relates to both TBM and roadheader tunnel and station excavations, respectively.

Muck handling will demand a reliable, durable and flexible conveyance system capable of accommodating removal, handling and conveyance of over 900,000 loose yards of excavated material derived from the excavation of TBM, roadheader, and excavations related to installation of support of excavation systems at portals, station entrances, ventilation shafts, and any temporary construction shafts as needed. In addition to this quantity, significant additional yardages may be required if cut and cover tunnel excavations are employed between the West Portal and the Metro Center station and the East Portal and the CBD East station or temporary construction shafts are required by the contractor. This yardage estimate does not include a double cross-over cavern, which may also be added back into the project.

Development of the running tunnel alignment should consider practical horizontal curves and vertical grade which can accommodate the proposed excavation and muck conveyance systems without imposing excessive restrictions or special requirements on equipment, i.e. customized TBM features. Typically, horizontal curves on the order of 22 to 25 times tunnel outside diameter and vertical grades less than 5% are considered acceptable.

This technical memorandum is intended to estimate the rough order of magnitude mucking quantities, explain the general nature of the potential mucking methods and facilities, identify critical restrictions on the means for mucking the required excavation volumes, and describe limitations for the proposed site facility locations during the project planning stage.

## 2.1 Overview of Muck Handling Plan

The handling and haulage of loose excavated material from the site will have a considerable impact on the local community. Possible impacts are noise, vibration, dust, traffic congestion, traffic accidents, damage to vehicles, and dirt tracked onto roads and highways. A well-conceived plan for the handling of muck on site and haulage from the site needs to be developed for this aspect of the project. The drivers of the muck handling plan include the following;

- Optimal on-site handling of large volumes of muck
- Environmental/economical haulage of muck from the project site
- Minimal impact to the local residential and commercial community
- Ultimate destination of the spoils.

Comparisons between alternative methods of muck handling must consider their respective objective values based on every relevant criterion. The ultimate decision on a mucking method, chosen from among all of the available methods, will ultimately depend on the microeconomics of the specific contractor selected for construction of the project as well as the project environmental constrains including third party approvals.

## 2.2 Assumptions

This memorandum has been prepared using the following assumptions and inputs:

- The project alignment is as provided on March 8, 2019 (an updated alignment will be issued by the end of July 2019)
- The project alignment includes consideration of 9 existing adjacent buildings and their foundations (as of July 2019 the effort to identify affected subsurface structures and foundations along the alignment corridor is still undergoing)
- Ground conditions are based on data presented in the February 28, 2019 Draft Geotechnical Data Report prepared by Alliance Geotechnical Group (as of July 15, 2019, the Final Geotechnical Data Report is still pending)
- Commerce Station location is between STA 71+13.15 and STA 77+38.15 (in July 2019 it is expected that the station location will be adjusted to the west by approximately 350 feet as part of an updated alignment that would be issued by the end of July 2019).

# 3 MUCK HANDLING FOR TUNNEL AND CAVERN EXCAVATIONS

The muck handling conveyance system for the DART D2 running tunnels and station cavern excavations will demand a reliable, durable and flexible conveyance system capable of accommodating removal, handling and conveyance of more than 900,000 loose yards of excavated material derived from TBM, roadheader, and, less likely, drill-and-blast portal and underground excavations. The total quantity of loose excavation is based on the bank excavation volumes multiplied by an appropriate bulking factor depending on the composition of the excavated material and the excavation methodology. These order-of-magnitude excavation volumes will be updated for the 30% design package according to the designer's spoil disposal plan report. The muck conditions will greatly vary depending on the type of excavation methods used for the particular structures (station caverns, entrances, tunnels, cross passages, shafts, plenums, cross passages, and pump stations) and the geological material/conditions encountered. In addition to this quantity, significant additional yardages may be required if cut and cover tunnel excavations are employed between the West Portal and the Metro Center station and the East Portal and the CBD East station.

The complicated excavation effort for the station caverns, entrances, and auxiliary areas will require a multi-level rock excavation effort by roadheader, which may be carried out by mucking through either twin bore tunnels which in turn may be excavated by roadheader or TBM. Alternatively, this material will be required to be hoisted from a mucking shaft in the vicinity of the cavern excavation. Currently, use of drill and blast excavation on this project is precluded due to vibration issues.

The types and order-of-magnitude estimate of mucking volumes are provided in **Table 1**, which has been included as **Attachment 1**.

The table indicates the various underground structure and material types which will pose excavation challenges. An innovative and flexible muck haulage system will be required to permit future modifications for handling muck produced from station caverns, entrances, auxiliary caverns, and portals, as well as from the running tunnels.

## 3.1 TBM Tunnel Mucking Operations

Due to the short length of the alignment, under two miles, an intermediate access shaft to the tunnel designated for haulage will be impractical. Access to a TBM driven tunnel for mucking will only be achieved from the East Portal or West Portal, at the open cut for the portal facility.

The mucking for TBM operations will, therefore, be carried out from a designated TBM launch site at one of the portal excavation areas designated by the project sponsor and indicated on the DART D2 project plans. In addition to mucking, this site will be used for transportation of tunnel lining segments, construction materials, supplies, and personnel.

TBM tunnel mucking systems consist of track haulage or belt conveyor type systems, depending upon the specific tunnel project conditions. Processing of the excavation muck may be required to accommodate use of belt-conveyor systems.

## 3.2 TBM Track Haulage Systems

Track haulage is energy efficient, compatible with most excavating and loading methods, and adaptable to most tunnel sizes. Track haulage is recommended up to 25 foot diameter sized tunnels. This is due to two reasons. First, the muck volume per advance length is very large, causing the muck cars used for haulage to be very large and consequently less efficient. Second, it is very difficult to recover derailments for such large sizes of loaded muck cars. Risk and safety becomes a serious concern. Long TBM drives with track haulage systems generally set up the number of cars per individual muck haulage train to match the theoretical rate of advance of the machine. The number of trains is then determined to eliminate wait time, where the TBM is waiting for trains to return to the TBM loadout area. As the length of the tunnel is increased additional trains are added on. This mucking concept is made possible by the use of California switches which allow multiple muck trains to pass each other in the main tunnel, sharing a single track. Concurrent with track muck car haulage, the trains can also accommodate special cars such as tunnel segment cars, man-rider cars, mortar cars, and flat cars for materials, supplies, ventilation tubes, etc. Depending on the tunnel diameter, single or double track systems could be used. However, single track system with California switches are most commonly used for this TBM diameter range. For short tunnel drives California switches may not be necessary. Additionally, double or triple tracks may be used in the portal or launching area.

Tunnel locomotives for underground use on metro projects can be diesel-electric, battery operated, or trolley-electric. The tunnel locomotives can be in the range of 25 to 55 tons, with a rail gauge of 600mm, 762mm, 900mm, etc. One of the primary considerations for determining the type of locomotive is diesel emissions. Diesel locomotives require an additional ventilation

rate of 100 cubic feet per minute of airflow per brake horsepower of all underground locomotives compared to electric locomotives. Some locomotives may also require a greater amount of air to ensure that the allowable levels of carbon monoxide, nitric oxide, and nitrogen dioxide, are not exceeded. (29 CFR 1926.800 k 10 ii, 2013) It is not uncommon for a tunnel construction project to have both diesel-electric and battery operated locomotives running underground concurrently.

When loaded muck trains return to the designated staging area of the tunnel, the muck can be hoisted to the surface with clamshells, skip buckets, or cranes. Clamshells are typically used in shallow tunnels. Cranes are more economical in medium depth tunnels. Where cranes are used, there must be adequate swing area around the access point to the rail cars, which may be on the surface or at the bottom of a shaft. Muck stock piles can then be loaded out into haul trucks or rehandled to another stockpile area by front end loaders. A skip with a headframe is generally used for deep tunnels.

## 3.3 TBM Conveyor Haulage Systems

Continuous belt conveyor systems are a contributing factor to a high percentage of production record holding tunnel drives. For instance, the Deep Rock Tunnel Connector project in Indianapolis, IN set world records for best day (409.8 feet), best week (1,690 feet), and best month (5,754.6 feet) for a 20 foot diameter machine (Robbins, 2018) with a belt conveyor system while a couple miles into the tunnel drive. Belt conveyers have the advantage of providing a continuous high capacity mucking system. However, this advantage is offset by an increased maintenance requirement and additional capital cost relative to track haulage systems.

The key component of the belt conveyor is the belting itself, which can be steel cable belt or fabric belt depending upon the needs of the specific project. Horizontal belt conveyors can be crown mounted, or side mounted, allowing the track haulage system to remain functioning for haulage of materials, supplies, segments, etc. Self-adjusting curved belt idlers allow the use of conveyors on alignments with curves, excluding extensive reverse curves.

There are numerous components of typical TBM belt conveyor haulage systems, which include the following;

- Horizontal belt conveyors
- Curved horizontal belt conveyors
- Main variable speed constant torque belt drives
- Advancing tail piece (Articulated tail pulley)
- Tripper booster drives
- Belt cassettes
- Emergency stop switches at regular intervals
- Inclined belt conveyors

- Vertical bucket conveyor systems
- Underground transfer station belts
- Stacker belts on the surface
- Overland belt conveyors on the surface
- Radial stacker belts on the surface
- Loadout bins on the surface.

Typically, the site facilities will include a radial stacker belt with a minimum 60° horizontal rotation enabling muck distribution into multiple stockpiles. A radial stacker belt maximizes efficiency by storing as much material as possible in a compact area. A typical radial stacker capacity of 8,000 cubic yards can be expected to hold several days of TBM production.

## 3.4 Designated Site Facility for Roadheader Tunnel Construction or TBM Launch Site

As noted in Drawing Civil-001, the designated site facility for roadheader tunnel construction or TBM launch site for this project is at the West Portal. This site is located between McKinney Avenue and Corbin Street bounded by Old Griffin Street and Magnolia Street. A typical site facility diagram for this type of project is provided as **Attachment 2**.

An additional site facility for roadheader tunnel construction and or cut and cover tunnel construction can be comprised from the site for the cut and cover CBD East Station. This area may also be utilized for TBM retrieval. This area is not expected to be utilized as a TBM launch site.

Site restrictions for these areas are as follows;

### 3.4.1 GENERAL RESTRICTIONS

- Lane closures shall be limited to off-peak traffic times
- No lane closures between Thanksgiving and New Year's Day
- Two lane closures shall be limited to weekends only

#### LIMITATIONS ON TRUCKING

- Limitations on trucking, including allowable lane closures and limitations on truckloads or routes will be provided by DART.

#### LIMITATIONS ON WORK HOURS

- Dallas, Texas City Code, Chapter 30-2 (h), 7:00 AM - 6:00 PM Weekdays.

ENVIRONMENTAL CONSIDERATIONS

- Dallas, Texas City Code, Chapter 43-139 ( c )(16), Conditions - Maintain the construction area in a public right-of-way in a manner that avoids dust, other health hazards, and hazards to vehicular and pedestrian traffic until the public right-of-way is permanently repaired.
- Dallas, Texas City Code, Chapter 30, Noise
- One hazardous materials site, rated as a high risk site is located within the designated location for the roadheader tunnel construction or TBM launch site. The LG Magnolia LP property, located at 1100 McKinney Ave., Map ID 174, was listed in the Activity and Use Limitations (AUL), Voluntary Cleanup Program (VCP), Municipal Setting Designation (MSD), and Groundwater Contamination Cases (GCC) databases. According to the database report (EDR, 2018), the earliest known date of detected contamination was 2007. The property received a certificate of completion through the VCP in 2007 for addressing soils and groundwater affected by volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), metals, total petroleum hydrocarbons (TPH), polychlorinated biphenyls (PCBs), and solvents. During the VCP process, the applicants agreed to accept an AUL, with MSD institutional controls. The site's proximity to the corridor and the nature of the database listings resulted in a High Risk ranking.

## 3.5 Roadheader Tunnel Mucking Operations

A roadheader is typically a rock excavator utilizing a boom-mounted cutter head, track crawler, loading scoop, gathering arms, and a conveyor system. The use of these machines is described in the main AMCR report and in the AMCR Technical Memorandums 1 and 2. Mucking for roadheader operations is very flexible, consisting of mobile equipment or belt conveyors. For a tunnel drive, the muck is transported back to the tunnel staging area at the portal site facility.

### 3.5.1 LOAD HAUL DUMP (LHD) UNDERGROUND MINE LOADERS

Mucking from roadheader operations can typically be achieved with the use of underground vehicles such as 8 cubic yard diesel Load Haul Dump Mine Loaders. These larger haulers are designed to carry the muck some distance before discharging to a feeder, hopper, or crusher, which may be underground or on the surface. There is an extensive range of bucket size options available to match project specific conditions, maximize productivity, and provide overall flexibility to the mucking system.

An LHD is similar in appearance to a conventional front-end loader, except that it is slower, very stable under heavy load, has 50% greater bucket capacity, a slightly smaller engine, and generally superior underground emission exhaust characteristics. (Tatiya, 2013) More than 75% of the world's underground production metal mines use LHDs to drive small and large sized tunnels, chambers, and wide excavations. Its longer, lower, narrower profile makes it particularly adaptable to tunnel excavations where width and height clearances are important. Central articulation provides perfect tracking and greater maneuverability underground.

As an alternative to LHDs, underground mine trucks can be used to haul the muck out of the tunnel. These are less flexible, but provide increased productivity under the right circumstances.

### 3.5.2 CONVEYOR BELT HİAULAGE FOR ROADHEADERS

Alternatively, excavation yardage from roadheaders can be carried to the end of the tunnel on a belt conveyor. In this case the excavated material must be trammed from the tail end of the roadheader to the hopper, crusher, or feeder of the belt conveyor system with smaller underground scoop trams. A scoop tram is also similar to a front-end loader, articulating in the center with a large bucket in front that transports ore in an underground mine. The operator sits at sideway controls facing the loader and drives it in either direction as required. This equipment is suited for loading muck and making short hauls to loading facilities. The muck would subsequently be transferred to the outside site facility area. The scoop tram is used to bridge the gap between the mobile tail end of the roadheader and the stationary hopper on the conveyor. This adds overall flexibility to the mucking system.

## 3.6 East and West Portal Mucking Operations

Mucking for the East and West Portals will handle primarily fill and expansive soils, potentially with soft rock at the bottom of these open cut excavations. The Dallas area is in the Blackland Prairie, with soils associated with the Austin chalk, Ozan marl, and Eagle Ford shale soft rock masses being excavated at these areas. Some of these soils tend to act like a sponge, expanding when water is absorbed. Expansive soils can cause material handling difficulties which the haulage system must be sufficiently flexible to handle. It can be expected that the mucking system for these portals will consist of a hydraulic track excavator with a bucket compatible with the encountered soil conditions assisted by multiple standard dump trucks.

## 3.7 Mucking Station Cavern Excavations from Cavern Mucking Shafts

Theoretically, the ideal means for mucking the volume of excavated material from an underground excavation is to provide the shortest possible travel distance from the centroid of the volume of excavated material to a loadout point on the surface directly adjacent to and above the underground excavation. This is the strategy adopted by mining companies for the development of orebodies in remote areas. For underground station cavern excavation in dense urban areas, this is usually difficult to achieve. For instance, while the 86th Street Station Cavern and 72nd Street Station Cavern for the Second Avenue Subway Project in Manhattan, New York were mined from mucking shafts directly adjacent to the cavern excavation, the East Side Access (ESA) Train Station Cavern was mucked to a mucking shaft located over four miles away in Long Island City, Queens, New York. (Wang, 2013) The economics of mucking a subway station cavern in an urban area is therefore highly dependent on the specific conditions of the overall project. In addition to the project specific conditions, the economics is further dependent upon the contractor selected and his selected means and methods. It is therefore imperative that the general nature of the mucking quantities and, more importantly, any critical restrictions on the means for mucking are determined during the project planning stage.

### 3.7.1 POTENTIAL METHODS OF CAVERN EXCAVATION AND MUCK HANDLING

There are several methods of excavating the station caverns for the DART D2 project, including roadheader, drill and blast, and mechanical excavators. It is likely that the excavation will be carried out by roadheaders, as with the DART City Place Station. Muck handling will be carried out with conveyors or mobile equipment, either via the tunnel portals or mucking shafts to the surface.

#### CAVERN EXCAVATION METHODS

The typical mined subway station cavern excavation method is by one of the following three methods; roadheader, drill and blast, or excavator. For the DART D2 project the most likely method of excavation is roadheader. This is because the Unconfined Compressive Strength (UCS) of the Austin Chalk at the project site ranges from 615 to 4,159 pounds per square inch (psi) and averaging 2,468 psi, (Ciancia, 2019) is in the low end of the range of rock being capable of being mined with a roadheader, which is up to 20,000 psi. The upper end of the Austin Chalk UCS is so low in the range of applicability of roadheaders, that the Cerchar abrasivity value is not a factor in determining the economics of this method. An excavator with sufficient capacity and an appropriately-sized bucket might be capable of cutting the Austin Chalk, however, the economics of this method may not be competitive for most contractors. Drill and blast may be limited due to vibration issues. At the present time, drill and blast is precluded by the DART Design Criteria manual for underground construction, Section 18.3.2 Excavation Methods, which states that blasting will not be permitted. Hence mechanized excavation equipment such as roadheaders and hoe-rams will be employed. Roadheaders will facilitate excavation of non-circular geometry SEM structures such as cross-cut adits with minimal over-break. Roadheaders were used for excavation of the Austin Chalk on the previous subway station cavern in Dallas, City Place Station, justifying this method as a most likely option.

#### CAVERN MUCKING METHODS

Mucking for mined subway station cavern excavations is typically carried out via a mucking shaft. The mucking shaft can be a separate temporary shaft designated for mucking only during construction or a permanent shaft concurrent with a station access location. Regardless of the type of shaft, the muck spoils volume can be hoisted to the surface by specialized equipment including cranes, skips, or vertical bucket conveyor systems.

The cavern mucking system should be compatible with the anticipated cavern excavation system. For the anticipated roadheader excavation several mucking options are available. Specifically, the muck from the anticipated roadheader excavation would be collected by the apron of the roadheader and transferred via belt for loading into the bucket of a rubber-tired load-haul-dump (LHD) or dumped directly into a wheel-mounted skip bucket. For the LHD option, the muck could be transferred directly to a fixed conveyor belt system comprised on a horizontal section near the mucking shaft which is connected to a vertical belt frame mounted to the side of the shaft, as shown in **Figure 3-1**.

**FIGURE 3-1. FIXED CONVEYOR SYSTEM INCLUDING HORIZONTAL AND VERTICAL SYSTEMS**

(a) Vertical bucket conveyor at top of shaft


(b) Fixed horizontal belt conveyor at bottom of shaft

Alternatively, the muck may be transferred directly from the tail conveyor of the roadheader into a wheel-mounted skip bucket. A track-mounted or gantry crane located at the top of the mucking shaft would then hoist the skip bucket to the surface. Typical dimensions of the mucking shaft to accommodate the vertical belt outfitted with 48-inch wide by 1'6" deep buckets are on the order of 30-ft inside diameter. This diameter would provide room for emergency manway access and service lines for ventilation, water supply and discharge, and power. For a typical 20-cy capacity skip bucket having approximate dimensions of 8-ft wide by 12-ft long by 6-ft high, a minimum inside diameter of 20-ft would be needed. The shaft interior is typically outfitted with fixed guide structures such as vertical partitions to facilitate safe hoisting.

Ultimately, the selection of the appropriate mucking system to be employed at each of the stations will depend on site constraints such as available surface area, as well as presence and proximity of sensitive building and/or structures.

### 3.7.2 GENERAL REQUIREMENTS FOR CAVERN MUCKING SHAFTS

Mucking shafts are typically 30 to 45 feet wide and may be rectangular or circular. These shafts must accommodate a considerable flow of mining personnel to the cavern, as well as materials and supplies for excavation and construction. Logistics areas for the inflow of personnel, materials, and supplies, and the outflow of excavated muck from the cavern must be provided at the surface adjacent to the shaft. These requirements typically place the construction activity in close proximity to the urban environment, raising safety and environmental concerns.

For safety, a standard OSHA safety barricade must be erected at the top of the shaft preventing accidental falls into the shaft. Alternatively, and particularly with skip or bucket conveyor systems, expanded metal fences are used to preclude access to dangerous locations.

Another safety feature that must be located at the top of the mucking shaft is a ventilation fan with a ventilation line, typically 36 to 84 inches, extending down the shaft to provide ventilation airflow to the underground works. This is typically a medium pressure fan with an airflow requirement of 200 cubic feet per minute of airflow per person underground, 100 cfm per brake horsepower of operating diesel equipment underground, and sufficient additional airflow to dilute toxic, flammable, and explosive gasses. (29 CFR 1926.800 (k). These fans produce a lot of noise and must be operated continuously. While silencers are available, these fans do present a nuisance to people in the nearby community.

Another safety feature of mucking shafts is two means of egress, primary and secondary, from the underground works. This requires a minimum of one scaffold stairs or enclosed ladder which must run continuously from the head of the shaft to the shaft invert. If a second scaffold stairway or enclosed ladder is not convenient, a man basket hoisted by crane may be used.

In an urban environment, enclosure of the facilities at the head of the shaft are typically required to prevent dust from causing a nuisance to neighbors. This will require construction of an elevated muck house to preclude dust from escaping the system at transfer points. There may also be noise restrictions at certain times during the day.

Space must also be provided in the shaft cross section for intake water lines, discharge water lines, compressed air lines, telephone communications, and electrical power.

To protect the conveyor belt especially the neoprene buckets of the vertical belt from damage due to errant steel associated with the ground support and/ or break-in walls the use of magnets at heading before introducing muck to the belt. The magnet collects the steel before damage to the conveyor could occur. The magnet is continuously monitored during the mining and any collected steel fragments promptly removed and disposed of.

## BUCKET CONVEYOR SYSTEMS

If a vertical bucket conveyor system or a skip system is employed, there must be a structural system also in the vicinity of the head of the shaft for conveyance to a loadout bin or overland belt conveyor.

The use of neoprene for the side and front panels of bucket for the vertical conveyor belt provides a durable easy to maintain material which also helps facilitate repair and replacement of worn or damaged parts. Specifically, neoprene panels are joined at the corners by welding, and thus allowing only the damaged panel to be removed and replaced while leaving the undamaged panels of the bucket in-place. For the East Side Access project, bucket repair was performed in-place using specialized glue and heating devices to vulcanize the rubber panels together for prompt repair. During the winter, a wooden shelter was constructed to enclose the top of the vertical belt as protection from the elements, allowing repair to proceed in a controlled environment.

## SHAFT SKIP HAULAGE SYSTEMS

Among the different alternative mucking systems available for use in mucking, shaft skip hoist haulage systems have been the most widely utilized system for mucking excavations that lie far below the surface, say below 350 feet and with haulage rates exceeding 60,000 tons per year. A comparison between ramp/truck haulage versus shaft skip hoist haulage concludes as follows; (Elevli, et. al., 2002)

- Total investment cost for shaft hoisting and ramp haulage increases almost linearly with depth. However, the slope of shaft hoisting is bigger than the slope of ramp haulage.
- Total transport cost for ramp is higher than the cost of shaft hoisting below 1,200 feet in depth. This criterion indicates that ramp haulage has a cost advantage over shaft hoisting for upper levels in earlier depth. After the depth of 1,200 feet, shaft hoisting becomes superior over the ramp haulage.

While the haulage rate may be feasible, the DART D2 project is primarily a horizontal structure, while skip haulage systems are typically set up for vertical haulage. The cost advantage for mucking may favor ramp/truck haulage, nevertheless, local economics may ultimately allow for a shaft skip hoisting system if access shafts are allowed for station cavern excavations.

## CRANE HOISTING SYSTEMS

Three alternative types of crane systems are available for mucking from shaft excavations at station cavern locations as follows;

- Truck Mounted Hydraulic Cranes

- Overhead Traveling Cranes
- Tower Cranes

Any of these alternative methods for crane hoisting of excavated materials can be considered for use on the DART D2 project. Due to their extreme flexibility, the most likely alternative will be truck mounted hydraulic cranes.

### TRUCK MOUNTED HYDRAULIC CRANES

Truck mounted hydraulic cranes are commonly used on tunneling projects due to the short durations of the project. Advantages for truck mounted hydraulic cranes include the following;

- Highly mobile, with highway speed capabilities
- Quick travel time and set up time
- Very flexible and inexpensive
- Long reach, high capacity booms
- Extensive standard crane features
- Can be rented hourly.

Disadvantages to these systems include;

- Requires space at ground level to move around and set up
- Requires an access road and crane mats.

### OVERHEAD TRAVELING CRANES

Overhead traveling cranes are commonly used at the tunnel portal area handling materials. Advantages for overhead traveling cranes include the following;

- Set up in fixed location is required
- More appropriate for hoisting materials and personnel.
- Efficient use of headroom space
- Computer aided crane operation
- More appropriate for hoisting materials and personnel.

Disadvantages to these systems include;

- Capacities tend to be limited
- Haulage and hoisting spans a limited coverage area
- Fixed beam support system is required

### TOWER CRANES

Tower cranes are not commonly used for mucking excavation yardage on tunneling projects because they are more suited to handling materials than hoisting excavated materials in large volumes. Advantages for tower cranes include the following;

- Used extensively in construction to hoist materials
- Can be set up above urban structures
- Convenient for use in confined urban areas
- Provides a good combination of height and lifting capacity
- Allows 360 degree rotation
- May be operated remotely.

Disadvantages to these systems include;

- Not typically used for hoisting people and excavated materials.
- May require a second crane to disassemble

### ALIMAK SYSTEMS

Alimak construction hoists consist of the following systems;

- Rack and pinion lift mounted on a modular frame mounted to the side of the mucking shaft. These hoists can be used in shafts for haulage and lifting of materials and personnel, and are ideally suited for providing the secondary, emergency vertical access required by mine safety regulations of 29 CFR 1926.800 (b).
- Main wire rope hoist is suitable for carrying heavy loads at relatively fast speeds and is the primary means of vertical access for men and materials in an underground mine.

These haulage systems are designed and manufactured for mining applications and are reliable even in the toughest shaft haulage environments. These have been used in construction for over 50 years in many types of applications and are common in underground mining, building construction, refurbishment, chimney/slipform, offshore, and bridge construction. The standard range of Alimak construction hoists is for low-rise, medium-rise, and high-rise constructions of all types.

### MUCKING SHAFT SPACE REQUIREMENTS

For efficiently handling large volumes of muck, radial stacker conveyors can be used to stockpile material prior to hauling away from the site. Stacker conveyance belts transfer muck from the overland transfer belt conveyor to the stockpile(s). The stacker may be fixed or radial type depending upon the anticipated muck volume generated. For greater muck generation, the use of a radial-type stacker conveyance belt enhances mining production by allowing tunnel muck to be placed into multiple stockpiles simultaneously. For example, as shown in **Figure 3-2** for the MTACC/LIRR's East Side Access project the stacker belt was designed to pivot radially by approximately 30 degrees to either side, hence load multiple stockpiles simultaneously. Dump

trucks would subsequently be loaded by excavator from the stockpiles for off-site haulage and disposal. Depending on the stockpile yard dimension and shape, longitudinal stacker belt systems may also be employed. It is common that overall production rates for large cavern excavations are limited by the amount of muck that can be stored on site and the speed at which it can be removed from site. This situation is called 'muck bound' and has a detrimental impact on production cost and schedule. Therefore, it is critical to provide the largest possible construction staging areas in order to achieve the greatest economy.

The typical space requirements for stacker belt system would be on the order of 50-ft long to over 200-ft long and could be modified based on site clearance constraints.

**FIGURE 3-2. RADIAL STACKER BELT CONVEYOR LOADING ONTO STOCKPILES IN SUNNYSIDE YARD (EAST SIDE ACCESS PROJECT)**

Source: East Side Access Project

In addition to accommodating muck haulage, the surface space requirements at the top of mucking shaft should be sufficient to accommodate operating a suitably-sized crane for lowering and hoisting necessary equipment, parts and materials for shaft and tunnel construction. In addition, a minimum of two to three-lane (typically includes the parking lane) of street should be provided for delivery and off-loading of material and equipment to the shaft. Adequate material and equipment storage space should also be available near the top of the shaft. To efficiently support station cavern and tunnel excavation and construction activities, the top of the mucking shaft should also provide surface space for the following functions;

- two means of emergency egress
- construction power
- plant and services including electrical switchgears
- ventilation vane axial fans
- sedimentation tanks
- air, water, and discharge supply lines
- material and supply haulage
- communication lines
- grouting silo and batch plant (depending on means-and-methods).

Limitations on the use of radial stackers include space, truck traffic patterns, proximity to traffic and pedestrians, dust and noise restrictions, etc. **Figure 3-3** shows erection of a muck house enclosure over a mucking shaft at 72nd Street Station for MTACC's Second Ave Subway Phase I project. Note the two-story height to accommodate future overhead gantry (track haulage) crane system as well as exhaust ductwork to support the tunneling operations. This type of muck handling system, though more expensive than a radial stacker, can be used in constrained urban locations where radial stackers cannot be used.

Local ordinances governing trucking on streets in the vicinity of the cavern mucking shaft will dictate permissible hours of trucking operation and available haulage routes. Space is required for queing of trucks awaiting loading of muck from temporary stockpiles or muck houses, and wheel wash well stations. As shown in **Figure 3-3** a muck house enclosure over the mucking shaft at 72nd Street Station for the Second Avenue Subway project in Manhattan's Upper East Side neighborhood helped contain noise and dust from mucking and loading operations. Rolling doors at each end of the muck house provided access and exit of haulage trucks facilitating the loading of trucks. Alternatively, the limited availability of surface space at station cavern mucking shafts located within congested downtown street right-of-way combined with restrictions on connecting haulage routes would favor a continuous conveyance system over traditional truck haulage.

**Figure 3-4** provides a view looking up and looking down for the access shaft at 83rd Street for the 86th Street Station of the Second Avenue Subway. **Figure 3-4 (a)** shows a typical access shaft setup for a shaft that has not been set up for a mucking operation. This view shows compressed air, water supply, water discharge on the right wall. The Alimak on the opposite wall provides a primary means of emergency egress, as well as materials and supply haulage. A second means of egress is by man basket, suspended from crane. Some access shafts may also have scaffold stairs or enclosed ladders. A piece of orange mine ventilation duct is shown in the very top of the photo's view. Primary power and ancillary power cables are installed on the left side of the shaft. Left of center shows wire rope crane cables for suspending equipment and muck buckets. **Figure 3-4 (b)** shows decking plate over the access shaft. During construction two lanes were closed and three lanes remained open to traffic. Through the soil zone, the square shaft sidewalls were constructed with soldier piles and lagging. Below, in the rock zone, initial support was provided by rock reinforcement and steel fiber reinforced shotcrete.

A closed-top sedimentation tank, as shown in **Figure 3-5**, would be the preferred option for a street-level location. For restricted urban mucking shaft sites, a portable open-top sedimentation tank typically 8.5-ft W x 45-ft L x 11-ft H could be suitable for underground locations.

Considering these requirements, estimate a minimum excavation shaft footprint of 50-ft x 200-ft.

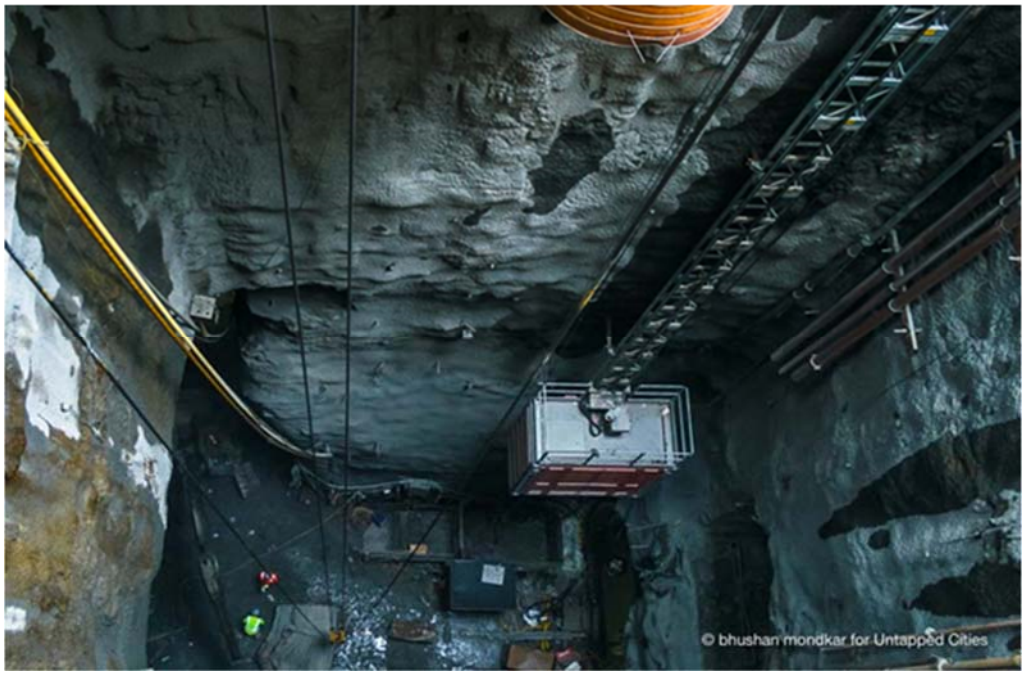
**FIGURE 3-3. MUCK HOUSE AT 72ND STREET STATION**

(a) Completed muck house showing proximity to traffic

(b) Mobilization and erection

(c) Erection of muck house showing 3 lanes open and 2 lanes closed

**FIGURE 3-4. ACCESS SHAFT AT 83RD STREET**

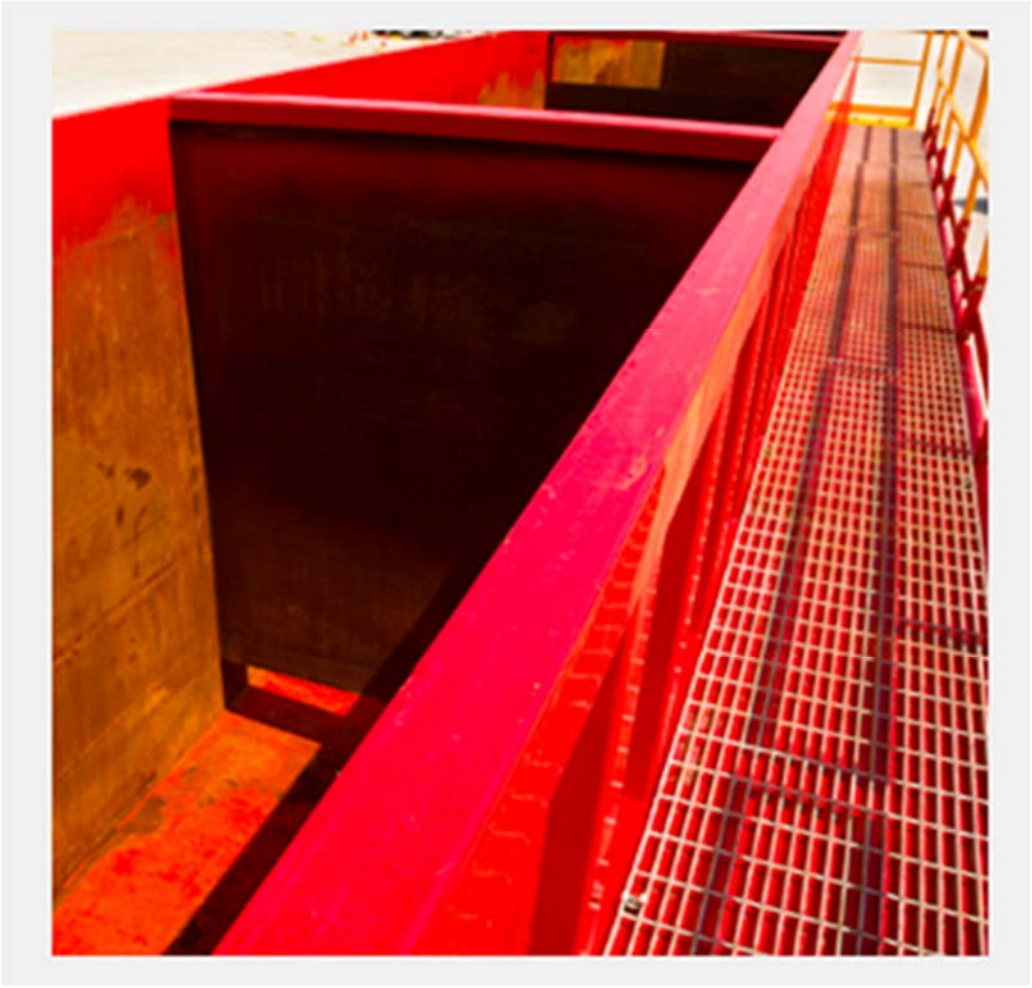



(a) View looking down – shows Alimak, air, water, and discharge lines

(b) View looking up during excavation of the shaft which is located in Second Avenue. Decking plate above designed to carry automobile traffic.

**FIGURE 3-5. PORTABLE SEDIMENTATON (FRAC) TANK - 21,000 GALLON**


(a) Insulated closed-top Frac Tank for use at street-level



(b) Open sedimentation tank for underground or secured site application

### 3.7.3 Available Surface Site Facility Locations for Cavern Excavation

The three surface areas where facilities are required for mucking, even if for small amounts of excavated material are Metro Center Station, Commerce Station, and CBD East Station. This includes mucking of entrance structures, ventilation structures, ancillary structures, and possibly the cavern excavation itself.

All construction activities, regardless of size, taking place in Dallas must comply with Dallas City Code Sec.19-118. (City of Dallas)

Construction activities that are ≥ 1 acre and < 5 acres, must comply with the Texas Pollutant Discharge Elimination System (TPDES) Permit rules and regulations for small construction sites listed in the TXR150000 Construction General Permit, in addition to Dallas City Code requirements.

Construction activities that are ≥ 5 acres, must comply with the TPDES Permit rules and regulations for large construction sites listed in the TXR150000 Construction General Permit, in addition to Dallas City Code requirements.

#### METRO CENTER STATION

##### GENERAL RESTRICTIONS

- Griffin Street may be required to remain open
- Access to Fire Station shall remain at all times
- Lane closures shall be limited to off-peak traffic hours
- Two or more lanes closed shall be on weekends only
- No lane closures between Thanksgiving and New Year's Day.

##### LIMITATIONS ON TRUCKING

- Limitations on trucking, including allowable lane closures and limitations on truckloads or routes will be provided by DART.

##### LIMITATIONS ON WORK HOURS

- Dallas, Texas City Code, Chapter 30-2 (h), 7:00 AM - 6:00 PM Weekdays.

##### ENVIRONMENTAL CONSIDERATIONS

- Dallas, Texas City Code, Chapter 43-139 ( c )(16), Conditions - Maintain the construction area in a public right-of-way in a manner that avoids dust, other health hazards, and hazards to vehicular and pedestrian traffic until the public right-of-way is permanently repaired.
- Dallas, Texas City Code, Chapter 30, Noise

## COMMERCE STATION

### GENERAL RESTRICTIONS

- Coordination with other construction activities around AT&T
- Lane closures shall be limited to off-peak traffic hours
- Closures of two or more lanes shall be restricted to weekends only
- No lane closures between Thanksgiving and New Year's Day.

### LIMITATIONS ON TRUCKING

- No muck house will be allowed in downtown for Commerce Station.
- No muck trucks will be allowed on Commerce Street.

### LIMITATIONS ON WORK HOURS

- Dallas, Texas City Code, Chapter 30-2 (h), 7:00 AM - 6:00 PM Weekdays.

### ENVIRONMENTAL CONSIDERATIONS

- Dallas, Texas City Code, Chapter 43-139 ( c )(16), Conditions - Maintain the construction area in a public right-of-way in a manner that avoids dust, other health hazards, and hazards to vehicular and pedestrian traffic until the public right-of-way is permanently repaired.
- Dallas, Texas City Code, Chapter 30, Noise
- Three indeterminate risk sites (sites where more information is needed to determine whether the site would pose a risk to the project) are located east of the Commerce Station.

## CBD EAST STATION

### GENERAL RESTRICTIONS

- Lane closures shall be limited to off-peak traffic hours.
- Closures of two or more lanes shall be limited to weekends only.
- No lane closures between Thanksgiving and New Year's Day.

### LIMITATIONS ON TRUCKING

- Limitations on trucking, including allowable lane closures and limitations on truckloads or routes will be provided by DART.

### LIMITATIONS ON WORK HOURS

- Dallas, Texas City Code, Chapter 30-2 (h), 7:00 AM - 6:00 PM Weekdays.

ENVIRONMENTAL CONSIDERATIONS

- Dallas, Texas City Code, Chapter 43-139 ( c )(16), Conditions - Maintain the construction area in a public right-of-way in a manner that avoids dust, other health hazards, and hazards to vehicular and pedestrian traffic until the public right-of-way is permanently repaired.
- Dallas, Texas City Code, Chapter 30, Noise
- Three indeterminate risk sites are located north, and one indeterminate risk site is located east of the CBD East Station.

### 3.7.4 SUITABILITY OF AVAILABLE SITE FACILITIES AT STATION CAVERN LOCATIONS

The site facility locations designated for mucking from the cut and cover excavations for Metro Center Station and CBD East Station are suited for this purpose. However, the limitations/restrictions at the Commerce Station cavern location is not well suited for optimized mucking operations. The two limitations on muck haulage, precluding both a muck house for Commerce Station and muck haulage trucks on Commerce Street dictate a less than optimal strategy for mucking the Commerce Street Station.

These limitations increase the cost of the project, have the potential to shift the economics of the project towards TBM, and increase the bid spread.

These limitations allow lane closures on Commerce Street, for construction of entrances and shafts, which may also include an access shaft to the cavern for delivery of supplies, shotcrete, concrete, forms, steel, HDPE waterproofing sheeting, pipe and duct sections, station components, etc. The limitations do not prohibit use of construction trucks, supply trucks, construction equipment, cranes, and such activities as ground improvement, utility relocation, repair, and monitoring, building monitoring, project logistics, etc.

## 3.8 Mucking Multiple Cavern Excavations from a Single Facility

In the event that the mucking operation for the station cavern excavations cannot be carried out with a mucking shaft adjacent to the individual station caverns, the excavated material may be carried back to a single designated site facility at the West Portal. With a great deal of difficulty, multiple cavern excavations can be mucked from a single mucking facility. However, running six to nine roadheaders in cavern expansions, possibly concurrent with TBM operations at a distance of up to one mile away from the site's sole mucking facility continuously for up to three years requires a very effective, robust, and flexible, means of mucking with conveyor belt systems.

This type of mucking system is likely to favor the use of high-speed belt conveyors despite the relatively short alignment distance, because augmenting rail haulage with California switches may not be a feasible option for several key reasons. (Wang, et. al. 2013). The tracks in the existing TBM headings are used for supplies while excavations are routinely operating directly adjacent to the TBM rail. Waterproofing, rebar, and structural concrete needs to be installed both immediately after completing TBM mining and immediately after excavating major caverns,

entrances, and ancillary structures. At any given time during the project the main track lines may be in constant use by any one of the mucking operations. Given the nature of the project, station caverns need to be fully waterproofed with a concrete final lining installed while excavation continues in other areas, potentially cutting off large quantities of remaining excavation from rail access. Such logistical difficulties along with numerous others require the project team to develop solutions to these muck removal issues.

Assuming the tunnel will be excavated from the West Portal, the muck from the tunnel excavation will be extracted from and then temporarily stockpiled near the West Portal, from within the limited surface space available there, muck will be hauled to a designated final deposit area depending on the type of muck. The hauling of the high muck volumes will be a critical operation and therefore the mode of hauling needs to be addressed early in the planning stage.

The alignment provided in the 10% design submittal considers two stations, Metro Center Station and CBD East Station will be constructed by the cut and cover methods. The two cut and cover stations will be mucked from the cut and cover locations at those stations. This allows multiple mucking options for the large excavation volumes at the Commerce Station. The presence of these mucking locations, nearby the Commerce Station via the newly excavated running tunnels allows consideration of these cut and cover excavations as the mucking shafts for the Commerce Station. This would require designing the muck haulage for these areas to accommodate the extra excavation volumes and daily production rates. Ultimately, there are several options for mucking the Commerce Station cavern excavation as follows;

- Mucking shaft at Commerce Station, if allowable and subject to restrictions.
- Mucking through the TBM launch area at the West Portal.
- Mucking through the tunnels to Metro Center and CBD East Stations.

These three options will affect the construction sequencing for the project.

A mucking shaft at Commerce Station will have the least mucking constraints, and consequently the shortest mucking time for the project. In this case, the running tunnels would be divided into four sections, to the midpoints between mucking locations, and subsequently excavated by the roadheader method. This may ultimately shift the economics for the project in favor of the roadheader method.

Without a mucking shaft at Commerce Station, the muck from the station excavation would be transported to the West Portal, probably by conveyor belt. For this to occur at least one tunnel would be required to be completed before excavation would be commenced. The excavation would then be commenced by enlarging the cavern excavation from the initial bored tunnels. This option would have a longer construction duration, but the impact on the community on commerce street would be reduced.

Mucking the Commerce Station cavern excavation from the Metro Center and CBD East Station cut and cover boxes would likely have an intermediate impact and construction period compared to the other two options.

## 3.9 Robust Muck Conveyance System Considerations

Considering the impacts of various muck removal options and the need for continuous system operation, an innovative robust system with high availability and reduced labor demands must be developed by the project team to help realize schedule savings. Key factors to take into consideration on all muck conveyance systems include the following (Wang, et.al., 2013);

- Minimize muck transfer points
- Minimize instances of routine maintenance items, if possible
- Commit to at least one scheduled maintenance shift per week to address issues which arise during production
- Ensure full auxiliary mucking equipment access around main dump points to alleviate muck buildup and unnecessary maintenance, especially if site geometry does not allow for clean-up conveyors
- Perform breakeven analyses regarding capital investments into the system versus schedule and labor savings with an increasingly efficient system to understand which will yield realized returns on investment.

# 4 DESIGNATED SITE FACILITIES

Allowing for either TBM or roadheader construction for the running tunnels, sufficient space at the portal facilities must be provided to the contractor for tunnel operations. Comparing between TBM and roadheader construction methods, TBM operations will generally require more site facilities and have therefore been conservatively used for sizing purposes described in the following paragraphs. A TBM with a diameter of approximately 22 feet will require a minimum of approximately 1.5 acres to allow for the TBM assembly. The designated site facilities will have to also accommodate workshops, temporary muck piles, loadout facilities, shipping containers, electrical power centers, material supplies, office space, bath houses, lubricant storage area, compressor houses, frac tanks, sedimentation ponds, and haulage truck queuing areas. The four acre site at the corner of McKinney Avenue and Old Griffin Street should be sufficient to accommodate these functions (This site is subject to change as the project progresses). If the TBM method is to be employed for excavation, a storage area for temporary precast segments (four production days) should be acquired by the contractor separate from the present site. The vacant area located opposite of Old Griffin Street, if available for acquisition, may provide sufficient space for segment storage.

The Drawing Civil-001 included as **Attachment 2**, contains a concept Site Facilities Diagram. It shows right-of-way lines for designated contractor areas at the west portal. Also shown is a typical layout diagram for the common facilities found on a tunnel construction site.

# 5 HAULAGE OPTIONS FROM DESIGNATED SITE FACILITIES

Highway transport is the most likely option for haulage from the DART D2 alignment. This option will impact the local streets and the community. Typically, a tandem dump truck can hold up to 18 cubic yards of material, though this figure is highly variable. At 18 cubic yards, 900,000 loose yards of excavated material will require haulage of 50,000 truckloads.

## 5.1 Loadout Facility Logistics

The logistics of the loadout facilities consist of a complicated system for truck haulage from the site. The characteristics of this system need to be considered, and limitations developed, during the planning stage of the project.

### 5.1.1 TYPES OF HAUL TRUCKS

The loading facilities for muck haulage from the site to its final destination will typically handle two types of haul trucks.

#### STANDARD DUMP TRUCKS

Typically consists of a truck chassis with a dump body mounted to the frame, with the bed capable of being raised by hydraulic rams. The typical arrangement is one front steering axle and one, 4x2, or two, 6x4, rear axles which typically have dual wheels on each side. Tandem rear axles are almost always powered, and front steering axles are also sometimes powered.

#### SEMI-TRAILER END DUMP TRUCKS

Typically consists of a 3 axle semi-tractor pulling a 2-axle trailer with dual tires, wherein the trailer contains a hydraulic hoist. These trucks have a large payload but may be unstable when the trailer is raised for dumping. Access roads should be wide and level for their use.

### 5.1.2 LOCATION FOR TRUCK ENTRY TO AND EXIT FROM THE SITE

Allowable restrictions on trucks hauling in the vicinity of the launch shaft, if any, are to be determined by DART. Ideally, one entrance and one exit would be provided in a continuous path, which would allow trucks to enter and exit the site without the need to reverse. This is typically considered the safest traffic flow pattern.

## 5.2 Alternative Haulage Options

### 5.2.1 RAIL HAULAGE

Rail haulage from the site is not an option for the DART D2 alignment.

### 5.2.2 MARINE BARGE HAULAGE

Marine barge haulage from the site is not an option for the DART D2 alignment.

## 5.3 Potential Muck Disposal Areas

Contractor will have to determine possible destinations for spoils derived from Austin Chalk, Eagle Ford Shale, and soil.

### 5.3.1 LANDFILL COVERINGS

Portions of the Austin Chalk might be suitable as a landfill covering material.

## 5.4 Contaminated Soils

For information on contaminated materials in soils, refer to the following report:

- DART D2 Corridor Hazardous Materials Existing Conditions, Technical Memorandum, Draft, February 1, 2019.

# 6 CONCLUSION

Muck handling for the DART D2 project will demand a reliable, durable and flexible conveyance system capable of accommodating removal, handling and conveyance of over 900,000 loose yards of excavated material derived from the excavation of running tunnels, stations, and excavations related to installation of support of excavation systems for portals, station entrances, and ventilation shafts. In addition to this quantity, significant additional yardages may be required if cut and cover tunnel excavations are employed between the West Portal and the Metro Center station and the East Portal and the CBD East station. This can be achieved with the various muck handling systems pertinent to roadheader and TBM excavation methodologies.

# 7 RECOMMENDATIONS FOR PE 20% DESIGN

## 7.1 Design Recommendation #1

### 7.1.1 DESIGN RECOMMENDATION

A mucking shaft on Commerce Street would be economically desirable. In the absence of a mucking shaft, excavated material from the Commerce Station excavation should be hauled to the surface via the West Portal or East Portal.

### 7.1.2 BASIS OF RECOMMENDATION

10% South of Swiss Alignment, March 8, 2019.

Verbal communication between HDR and DART (April 2019) indicating the DART preference not to allow a mucking shaft on Commerce Street.

Blasting is prohibited on the D2 Alignment.

Approximately 4 acres are available for logistics at the East Portal and somewhat less for the West Portal.

### 7.1.3 SOURCES OF UNCERTAINTY

Environmental studies and further communication with agencies, the local community, and potential stakeholders may lead to changes in restrictions on work in the vicinity of Commerce Station. Such changes will change the economics and required engineering recommendations for the project.

Special treatment of excavated material may be required, if the material is tested during construction as being contaminated.

# 8 CONSTRUCTION CONSIDERATIONS

## 8.1 Constructability Issues

As discussed in the following sections, muck handling involves several constructability issues.

## 8.2 Spatial and Geometry Requirements

There are approximately 4 acres available for mucking at the West Portal and at the east end of the alignment. This acreage is sufficient for the majority of the excavation volumes. Additional space may be accommodated at the Metro Center Station and CBD East Station, and at ancillary excavations for Commerce Station.

## 8.3 Environmental Considerations

One hazardous materials site rated as a high-risk site is located within the designated location for the roadheader tunnel construction or TBM launch site. The LG Magnolia LP property, located at 1100 McKinney Ave., Map ID 174, was listed in the Activity and Use Limitations (AUL), Voluntary Cleanup Program (VCP), Municipal Setting Designation (MSD), and Groundwater Contamination Cases (GCC) databases. According to the database report, the earliest known date of detected contamination was 2007. The property received a certificate of completion through the VCP in 2007 for addressing soils and groundwater affected by volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), metals, total petroleum hydrocarbons (TPH), polychlorinated biphenyls (PCBs), and solvents. During the VCP process, the applicants agreed to accept an AUL, with MSD institutional controls. The site's proximity to the corridor and the nature of the database listings resulted in a High-Risk ranking.

## 8.4 Availability of Materials

There are numerous vendors for mucking equipment and materials on the market.

## 8.5 Use of Non-Standard Materials, Construction Equipment, or Construction Means and Methods

Contractors are expected to use their own means and methods for mucking, to obtain an optimal solution. The use of non-standard equipment and methods to obtain an optimal solution is not discouraged.

## 8.6 Special Monitoring Requirements

Contractor should employ the most appropriate noise, vibration, and dust monitoring techniques.

## 8.7 Potential Causes for Delays

If additional contaminated soil and rock are encountered, this would result in additional time and expense to deal with these materials.

## 8.8 Potential Hazards

The mucking process is both labor and equipment intensive. Many potential hazards exist such as pinch points, moving vehicles and equipment, and blind spots. A well-executed safety program is essential.

# 9 REFERENCES

Ciancia, 2019, DART D2 - FIRST DRAFT Technical Memorandum #3, Preliminary Ground Characterization, Rev A, January 24, 2019.

City of Dallas, Construction Workshop, March 18, 2019, https://dallascityhall.com/departments/trinitywatershedmanagement/wheredoesitgo/Pages/Construction.aspx .

Code of Federal Regulations, 29 CFR 1926.800 k 10 ii, OSHA Construction Industry Regulations, U. S. Department of Labor, 2013.

Elevli, B., A. Demirci, and O. Dayi, Underground Haulage Selection: Shaft or Ramp for a Small-scale Underground Mine, Journal of The South African Institute of Mining and Metallurgy, July/August 2002.

Robbins Company, Weighing the Options; Is Industry Bias Towards New Machines Limiting? Tunnel Business Magazine, p. 16-20, June 2018.

Tatiya, Ratan Raj, Surface and Underground Excavations, 2nd Edition: Methods, Techniques, and Equipment, CRC Press, p. 181, 2013.

Wang, E. C., Julio Velez, and Vincent Prestia, Long Distance Inter-Boro Muck Conveyance Challenges, Rapid Excavation and Tunneling Conference, p. 765-772, 2013.

Workman, Dean, Extensible Conveyor Systems for Long Tunnels Without Intermediate Access, The Robbins Company, 7 pp. 2010.

# 10 ATTACHMENT 1: TABLE 1: ESTIMATED ORDER OF MAGNITUDE EXCAVATION YARDAGES

**TABLE 1: ESTIMATED ORDER OF MAGNITUDE EXCAVATION YARDAGES (OPTION 2: MINED RUNNING TUNNEL BEYOND THE WEST PORTAL)**

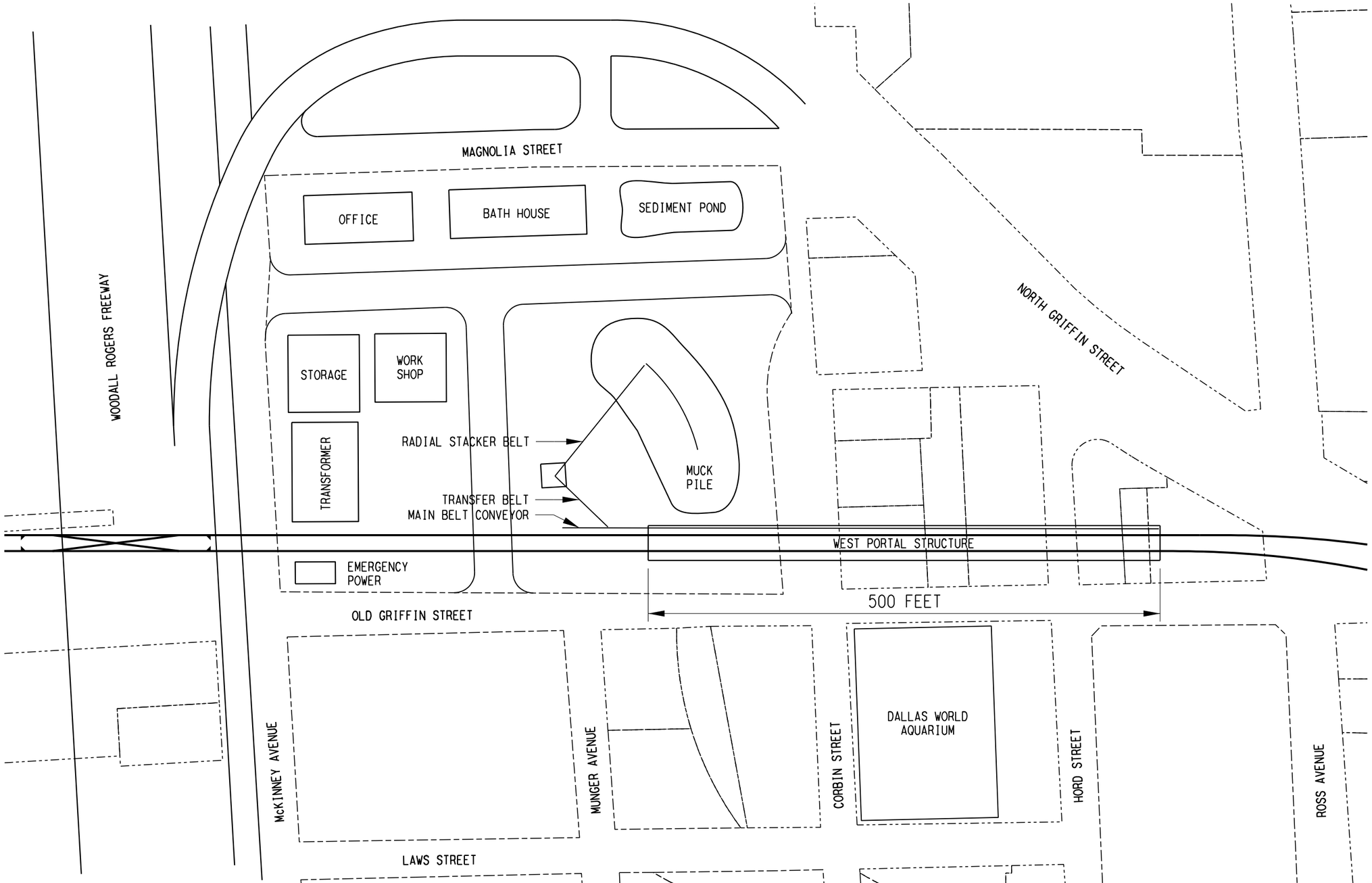
| Structure | # | From Station | To Station | Length (Feet) | Cross Section (Square Ft) | Bank Cubic Yards (BCY) | Swell Factor | Loose Cubic Yards (Yards) | Material |
|---|---|---|---|---|---|---|---|---|---|
| West Portal | 1 | 35+29.38 | 42+89.37 | 760 | 1,127 | 31,723 | 1.40 | 44,412 | Soil |
| Running Tunnel | 1 | 42+89.37 | 50+03.16 | 714 | 398 | 10,522 | 1.60 | 16,835 | Soil/Shattered Rock |
| Metro Center Station | 1 | 50+03.16 | 54+13.16 | 410 | 4,830 | 73,344 | 1.80 | 132,019 | Soil and Rock |
| Entrances and Ancilliaries | | ----- | ----- | | | 29,338 | | | Soil and Rock |
| Running Tunnel | 2 | 54+13.16 | 71+13.15 | 1,700 | 398 | 50,118 | 1.80 | 90,212 | Shattered Rock |
| Cross Passages | 1 | 62+63.16 | ----- | 18 | 176 | 117 | 1.80 | 211 | Shattered Rock |
| Pump Station | 1 | 66+00.00 | 66+00.00 | 18 | 375 | 250 | 1.80 | 450 | Shattered Rock |
| Commerce Station | 1 | 71+13.15 | 77+38.15 | 625 | 1,919 | 44,425 | 1.80 | 79,965 | Shattered Rock |
| Entrances and Ancilliaries | 1 | ----- | ----- | | | 17,770 | 1.80 | 31,986 | Soil and Rock |
| Running Tunnel | 2 | 77+38.15 | 89+00.00 | 1,162 | 398 | 34,253 | 1.80 | 61,655 | Shattered Rock |
| Cross Passages | 1 | 85+53.62 | ----- | 18 | 176 | 117 | 1.80 | 211 | Shattered Rock |
| Cut and Cover Tunnel (Wide) | 1 | 89+00.00 | 93+69.09 | 469 | 3,773 | 65,551 | 2.80 | 183,543 | Soil and Rock |
| CBD East Station | 1 | 93+69.09 | 97+54.09 | 385 | 3,000 | 42,778 | 1.80 | 77,000 | Shattered Rock |
| Entrances and Ancilliaries | 1 | ----- | ----- | | | 17,111 | 1.80 | 30,800 | Soil and Rock |
| Cut and Cover Tunnel (Wide) | 1 | 97+50.00 | 101+55.23 | 405 | 2,849 | 42,759 | 1.60 | 68,414 | Soil/Shattered Rock |
| East Portal | 1 | 101+55.23 | 107+60.00 | 605 | 784 | 17,561 | 1.40 | 24,585 | Soil |
| Sub TOTAL | | | | 7,289 | | 477,737 | | 842,298 | cy |
| Surcharge (10%) | | | | | | | | 84,230 | |
| | | | | | | | Approx. | 927,000 | cy |

Note 1: Swell factors from https://www.engineeringtoolbox.com/soil-rock-bulking-factor-d_1557.html
Note 2: Entrances are 40% of station cavern volume.
Note 3: Cross Sectional area of Metro Center Cut & Cover Station = 4,830 square feet.
Note 4: Cross sectional area of Commerce cavern = 1,919.14 square feet. (Single Arch)
Note 5: Cross sectional area of CBD East Cut & Cover Station = 3,000 square feet.
Note 6: Cross sectional area of Running Tunnel is based on TBM Excavation

# 11 ATTACHMENT 2: DRAWING CIVIL-001 SITE FACILITIES DIAGRAM

DWG No. HC2-0001

PLAN SEQ NO




SCALE (IN FEET)
0 25 50 100

NOTE:

1. THIS SITE FACILITY DIAGRAM IS BASED ON POTENTIAL DART ACQUISITION OF PROPERTY EAST OF OLD GRIFFIN STREET AND McKINNEY AVENUE.
2. ADDITIONAL OFFSITE AREAS FOR OFFICE AND LOGISTICS ARE TO BE OBTAINED BY CONTRACTOR.

NOT AN APPROVED DRAWING
PRELIMINARY 10% DESIGN

CONTRACT SHEET No. 0 OF 0

| REV | AMEND | CR | DATE | DESCRIPTION | BY | ENG | CHK | APP |
|---|---|---|---|---|---|---|---|---|

IN-PROGRESS

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DART PROJECT

DART



| | |
|---|---|
| SCALE | 1" = 50'-0" |
| DRAWN | K. SHEFFY |
| DESIGNED | A. STONE |
| CHECKED | V. CASTRO |
| IN CHARGE | A. STONE |
| DATE | 08 MAR 19 |

CAES

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

SITE FACILITIES PLAN

| CONTRACT | DWG No. | REV |
|---|---|---|
| C-XXXXXXX-XX | HC2-0001 | A |

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