SUBAQUEOUS INTERSTATE HIGHWAY TUNNEL
DESIGN AND CONSTRUCTION

Earl F. Cecil
Senior Structural Engineer
Palmer and Baker Engineers, Inc.
Mobile, Alabama

The Mobile River Tunnel located at Mobile, Alabama was conceived in the minds of Mr. Wayne F. Palmer of Palmer and Baker Engineers, Inc. and State Highway Officials in 1956. It was recognized at that time that the present Bankhead Tunnel would be overloaded in a very few years. The Bankhead Tunnel was built in 1939-41 with a 2 1/2 foot roadway and 1 3/16 feet and 7-1/2 inches vertical clearance at the ends. It was designed for a traffic volume of 12,000 vehicles on peak days. In the year 1956, 3.8 million vehicles passed through it, and 4.3 million in 1957, about 11,000 vehicles per day average the year-round and over 20,000 per day on weekends. By 1970 more than 20,000 vehicles per day average were going through its portals. The daily volume reached 25,900 on weekends.

The new Mobile River Tunnel was first designed as a two lane single tube tunnel to carry traffic east bound and would be used in conjunction with the Bankhead Tunnel which would be for west bound traffic.

The plan was abandoned because of the limited clearances both horizontally and vertically in the Bankhead Tunnel, and because the interchange in downtown Mobile would be very complicated.

It was then decided to design a four lane, twin tube tunnel to serve Interstate Highway I-10 independent of Bankhead Tunnel.

Tunnel Studies.

We studied two single tubes and double tubes of rectangular, elliptical and circular sections. Each section was studied with 24 foot roadways and 16 feet 3 inches vertical clearance for cost comparison. The twin circular tube was the most economical and practical to build and was selected for final design. We then made cost comparisons for 24 foot, 26 foot and 28 foot roads, all with 16 feet 3 inches vertical clearance over the gutter. The cost increased as the roadway was made wider, as we expected, but it was a much larger increase between the 26 foot and 28 foot roadways than between the 24 foot and 26 foot roadways. Since people have become accustomed to wider roads and bridges it was decided to use the 26 foot roadway design which gives greater safety.

Palmer and Baker Engineers, Inc., acting as Consultants for the Alabama State Highway Department, completed the design, plans and specifications after the State and the Bureau of Public Roads gave approval to the cross section and location of the tunnel.

Longitudinal Section.

The tunnel will be 3,000 feet portal to portal with a west side grade of 5.25 percent and an east side grade of 5.85 percent joined with a 900 foot vertical sag curve. The low point of the top of the tunnel is 56.75 feet below M.S.L. Low point of profile grade is 83.35 feet below M.S.L. The low point of the bottom of the tunnel is 96.55 feet below M.S.L.

The West Ramp is 738.4 feet on control line of west bound roadway and 690.0 feet on control line of east bound roadway. Most of the ramp is on a curve which limits the speed to 40 miles per hour.

The East Ramp is 717.9 feet on control line of west bound roadway and 713.6 feet on the control line of east bound roadway.

The ramps will be constructed to elevation 15.0 feet at the west grade point and 18.0 feet at the east grade point (to prevent flooding). The east end is three feet higher because it is exposed to high tides and waves from open water of Mobile Bay.

The West Arch section is 200 feet long from the West Portal to West Ventilation Building. The building is 50 feet joined to a 25 foot + transition section. All of these will be built in the dry. The east side will have a 225 foot arch section from East Portal back to the East Ventilation Building which is 50 foot long and will be joined to a 25 foot transition section. These parts will also be built in the dry and of course the ramps on both sides will be built in the dry.

The center portion of the tunnel is comprised of seven sections each 346 feet long, which are prefabricated of double steel shells with reinforced concrete inside the inner shell and ballast concrete between the shells. The tube sections are completed and moved into alignment of the tunnel and sunk into a prepared trench and connected to each other under water.

STRUCTURAL DESIGN

Ramps.

The ramps will be U-shaped with the bottom slab extended outside the walls to engage the weight of the overlying earth to resist the uplift of hydrostatic pressure. In the section of the west ramp adjacent to Fort Conde House the construction easement is so restrictive as to prohibit the slab extensions, so in this instance the base slab will be thickened to provide the required structure weight.

Waterproofing for the ramps, as well as all other built-in place structures, except transitions, will consist of a layer of brick-in-mastic under the base slabs and five-ply membrane waterproofing with a three inch thick protective layer of gunite concrete applied to all exterior surfaces up to elevation +15.0 on the west side and elevation +18.0 on the east side. The brick-in-mastic will be
laid on a six inch thick reinforced base slab which forms stepped horizontal surfaces approximately 10 feet wide. On the east side the base slab will be thickened as necessary to provide embedment for the bearing piles.

The interior surfaces of the ramp walls will be faced with dark-colored brick to reduce the glare. Median planters faced with dark brick will be provided to eliminate exposure to oncoming head lights in the adjacent lanes as well as for landscaping purposes. The two inch asphalt roadway surfacing will also serve to reduce glare and noise.

**Arch Sections.**

The arch sections between the portals and the ventilation buildings at each end of the tunnel will have the same interior configuration as the remainder of the tunnel except that there are no air ducts under these roadway sections. The interior of each tube throughout the length of the tunnel will be finished with light-colored ceramic tile on all surfaces above the tops of curbs to provide high light reflectance.

Drainage sumps will be provided immediately inside each portal to collect storm drainage from the ramp areas with sump pumps and controls housed in rooms located adjacent to the tunnel proper. The sumps will be the wet sump type with a concrete partition wall separating the sumps for each roadway for reasons to be discussed later.

Base slabs under the brick-in-mastic waterproofing will form horizontal ledges, as in the ramp sections, and thickened as required for bearing pile embedment on the east side only.

**Ventilation Buildings.**

The ventilation buildings will be rectangular structures 50 feet by 108.4 feet straddling the traffic lanes providing space beneath the roadways for ventilating fan chambers and side air shafts for fresh air intakes. The space over the roadways will be used for housing the electrical and mechanical equipment and repair shop. Additional floor space will be provided above grade to house the control boards and monitors, which are the nerve center of the operation. Architectural treatment of the above grade portion of the structure will be compatible with that of other structures in the area. Brick-in-mastic waterproofing under the bottom slabs, with five-ply membrane waterproofing protected by three inches of reinforced gunite concrete on the side surfaces up to elevation +15.0 will be provided.

An elevator in one air shaft and a stairway in the other air shaft at each building will serve landings at the fan chamber floor, roadway level, equipment room level and ground level. A system of overhead monorail hoists are so arranged at the fan level to service or remove any fan or motor and transfer it to a position under one of the air shafts. At the top of this shaft a hoist will be provided to raise or lower equipment through the shaft to or from a hinged grating covered landing platform at the equipment room level.

**Twin Tube Section.**

The cross section selected was 26 feet curb to curb with a minimum vertical clearance of 16 feet 3 inches at the curb. The clearance line inside the tunnel between portals is on a radius of 16 feet 3 1/8 inches, the center of which is located 6 feet 8 3/8 inches above the roadway. The vertical clearance at the centerline of the tube is 22 feet 11 1/2 inches above the roadway crown. Beyond the clearance line there will be 1 1/8 inches of tile and back up mortar, a 2 foot 0 inches reinforced concrete strength ring, a 5/16 inch steel waterproofing plate, a variable thickness of tremie concrete for ballast and protection of the water-tight plate, and the outside shell plate which acts as a form.

The twin tubes have a common center wall, but each is enveloped with a waterproofing plate. The roadways are 40 feet 4 inches to center, and the tube centerlines are 39 feet 8 1/2 inches apart.
The two roadways are interconnected by five passageways at which points control panels for emergency use are located.

**Transition Sections.**

At each end of the floated-in tube sections built-in-place transitions complete the connection to the ventilation buildings. This section carries the typical roadway configuration through it and forms a transition in the air duct from the shape common to the circular tubes to three seven-foot square openings under each roadway to fit the discharge housing of the ventilation fans. The entire reinforced concrete arch shaped structure will be enclosed in a watertight steel form plate covered with three inches of reinforced gunite concrete protection. Dowels from the tube sections will be provided to effect continuous structural integrity with the transitions.

**OPERATIONAL FEATURES**

**Ventilation.**

The tunnel will be ventilated by the semi-transverse method where air is furnished by three 100 horsepower, four-speed axial flow fans in each ventilation building for each roadway, a total of twelve fans, pulling fresh air through the stacks and distributing it over the length of the tunnel between buildings and the vitiated air exhausted through the portals. This method is in contrast to the longitudinal method that withdraws air from a small area near the center, such as at Bankhead Tunnel, or the full transverse method, such as at Holland Tunnel and other longer tunnels, which supplies and withdraws the air from the tunnel throughout its length by two separate air ducts.

With this ventilation system, based on 100 percent ventilation, air for each roadway will be provided to supply 170 cfm/linear foot of downgrade roadway, 225 cfm/linear foot of near level section, and 300 cfm/linear foot on the upgrade roadway. On this basis, 1,420,000 cfm is required for both roadways to provide a complete air change every 2.7 minutes. One hundred percent ventilation can be obtained with four fans operating in each roadway. Automatic controls provide for ventilation demand in five stages based on actual traffic volume. These stages will be controlled by a program control clock, which may be overridden by a traffic volume computer when peak traffic exceeds that normally programmed, and both may be overridden by carbon monoxide analyzers which take air samples automatically at several locations along the tunnel. Manual override control will be provided in case of need. Design is based on 2100 vehicles per hour each way with a peak rate of 3400 vehicles/hour/direction.

The ventilation system of each tube is designed for manual reversal of the fans so as to extract smoke and fumes in case of fire. For this eventuality, automatically operated sprinkler systems with fog nozzles will be located in each air duct near the normal fan discharge to cool the air being extracted, and thus protect the fans and motors from heat damage.

**Tunnel Lighting.**

The tunnel will be illuminated by means of continuous row fluorescent fixtures along the center of each roadway for the entire length. At the incoming portals four additional rows of fixtures will be installed to allow for adaptation from the bright outside roadway. As previously mentioned, the ramp roadway and walls will be constructed of dark colored materials to assist in this adaptation. Night lighting will be obtained by reducing the interior lighting to a low level, and illuminating the ramps by means of mercury-vapor fixtures.

Lighting will be controlled automatically by means of photo-cells to adjust for bright or cloudy day conditions and night operation. The design lighting intensities for the various lighting conditions are as follows: Night, 6 foot-candles throughout; Overcast day, 18 foot-candles throughout and 54 foot-candles at entrances; Bright day, 18 foot-candles throughout and 90 foot-candles at entrances. Lighting is based on a 50 MPH design speed.

**Drainage and Pumping.**

The tunnel will be equipped with pumping facilities at each portal and at mid-channel to provide a dry tunnel. Since there will be no restrictions as to the type of vehicle using the tunnel, all pumps are spark-proof with totally enclosed motors designed to discharge volatile liquids. The sumps for each roadway are separate and equipped with automatic temperature rate of rise actuated deluge systems of sprinkler water at the portals and foam at the mid-channel.

The portal sumps will collect storm drainage from the ramps via interceptors along the ramps and full-width roadway gratings at the portals. A full-width interceptor grating will be provided at the upper end of the east ramp which connects directly to the structures of the east interchange. At the west portal sump, four 40 horsepower pumps (1800 gpm at 50 foot head), including one spare, are provided. At the east portal sump, four 30 horsepower pumps (1300 gpm at 50 foot head), including one spare, are provided.

Four 25 horsepower pumps (250 gpm at 125 foot head), including one spare, are provided at the mid-channel sumps to discharge tunnel washdown water. These pumps will discharge through a header in an air duct to storm sewers near the east ventilation building. All pump operations will be automatic, actuated by float controls in the sumps.

**Power Supply.**

Power for the tunnel will be furnished by the Alabama Power Company from two of the most reliable power sources in the Mobile area, one from each bank of the river. Each feeder normally supplies power for half the loads in the tunnel but automatic transfer from one source to the other will be provided in case of power failure. If failure of both feeders should occur, a 500 KW auxiliary gas engine powered generator in the east ventilation building automatically starts and supplies power for emergency loads that require maintenance without interruption, such as emergency tunnel lights and building lights, closed circuit television, emergency telephone, fire alarm and traffic lights. The design includes a solid state uninterruptible power supply composed of batteries, rectifiers and inverters. Normal power distribution is 480V/277 volts, three phase.
Fire Protection.

Five connecting passageways between the tubes will be provided at strategic intervals within the tunnel for safe evacuation of persons in case of accident or fire and so that firemen may operate from a position of safety in the unaffected tube. In addition to the fire hose niches spaced at regular intervals, the crossover passageways contain all emergency controls, portable fire extinguishers, telephones to the control room and fire alarm stations connected to the Mobile Fire Department.

Traffic Control.

The normal tunnel operation will be automatic but inside the control room located in the east ventilation building, an operator will be on continuous duty monitoring every operation with a panel before him recording every function or operation within the tunnel. Fourteen closed circuit television screens will monitor every foot of roadway in each of the two tubes. Additionally, the operator may switch manually to two cameras located at strategic locations on the ramps.

At quarter points in each tube sound pick-up devices will be located so that they can detect unusual noise within each section of the tunnel such as a collision or horn blowing. These devices will have the ability to tune out the ambient noise and detect only the high decibel noises and will be connected to continuously open speakers on the monitoring panel.

Located throughout the tunnel, multicellular horns will be placed facing oncoming traffic at about 200 feet centers. The operator will be able to talk to motorists and give directions when emergencies occur. Located at about 200 foot intervals along each roadway, emergency telephones will be provided which upon pick-up are connected directly to the control room.

The Operator can control the traffic by means of lane control signals or stop incoming traffic at the head of the ramps by means of traffic signals as dictated by conditions. A continuous traffic patrol will be maintained by police on motor tricycles. Wreckers will be stationed at the ends of each ramp for emergency removal of vehicles.

TUNNEL CONSTRUCTION

The contract for construction of the Mobile River Tunnel was signed between the Alabama State Highway Department and the Mobile Tunnel Constructors, a joint venture of Winston Brothers Company, Atlas Construction Company, Ltd., and the Foundation Company of Canada Ltd. Construction began in October, 1969 and completion is expected by July, 1972.

The contract for tunnel and ramps was bid at 47.5 million dollars. The quantities of major items going into the construction of the tunnel and ramps are listed as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation (Dredging and Unclassified)</td>
<td>1,575,000 c.y.</td>
</tr>
<tr>
<td>Backfill (All types)</td>
<td>1,292,000 c.y.</td>
</tr>
<tr>
<td>Concrete (All classes)</td>
<td>221,130 c.y.</td>
</tr>
<tr>
<td>Reinforcement (All types)</td>
<td>7,200 Tons</td>
</tr>
<tr>
<td>Structural Steel (All shapes)</td>
<td>9,100 Tons</td>
</tr>
<tr>
<td>Steel Piling (Foundation)</td>
<td>76,000 L.F.</td>
</tr>
<tr>
<td>Bituminous Concrete</td>
<td>3,000 Tons</td>
</tr>
<tr>
<td>Membrane Waterproofing</td>
<td>26,000 a.s.f.</td>
</tr>
<tr>
<td>Brick-in-Mastic Waterproofing</td>
<td>23,000 a.s.f.</td>
</tr>
<tr>
<td>Pneumatically Applied Mortar</td>
<td>22,000 a.s.f.</td>
</tr>
<tr>
<td>Face Brick</td>
<td>340,000</td>
</tr>
<tr>
<td>Precast concrete coping</td>
<td>3,100 L.F.</td>
</tr>
<tr>
<td>Ceramic Tunnel Tile</td>
<td>385,000 S.F.</td>
</tr>
<tr>
<td></td>
<td>3,080,000 Tile</td>
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</tbody>
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Foundation Boring.

Foundation borings indicated the foundation soil under the floated-in tube sections and west ventilation building is generally a dense fine sand. Undercutting of a soft clay layer and replacement with well compacted sand will be required under a portion of the west ramp. Pile support will be required under the east ramp, arch section and ventilation building, and transition connection to the tube section.

On the east side of the river the excavation is mostly fine loose sand with soft clay layers. The bottom of the cut is in fine sand varying from loose to very dense. The cut section for the floated-in-place section is soft silty sand and clay at the top but gets into fine dense sand at the bottom with some stiff clay layers or pockets indicated.

The west side of the river has been filled with wharf construction material and other debris for several hundred feet back from the bulkhead line. The first 10 to 20 feet thickness is silty clay and sand containing miscellaneous fill material. This is underlain by a 2 to 11 foot thick layer of soft to medium stiff clay and then by medium dense to very dense sand.

SPECIAL CONSTRUCTION CONSIDERATIONS

The tunnel alignment on the west side of the river is south of Church Street and crosses the main line track of the L & N Railroad and many service tracks. It also crosses the north end of the freight depot and through the Railway Express Agency building, and several miscellaneous small buildings. These buildings must be removed and some relocated. The Contractor is required to maintain a minimum of three tracks open to traffic across the right-of-way at all times during construction. The tracks will be carried over the cut by three steel plate girder bridges. The tracks are above elevation 5.0 M.S.L., and clearance must be maintained underneath to float two of the tunnel sections under the bridges before they can be located and sunk. Careful and exacting step by step planning will be necessary to coordinate the cofferdam construction, track shifting and bridge construction. There are several buildings in the immediate area which must be protected during the construction including the City Hall complex, County Court House and a Church and many smaller structures.

The east side is less complicated, but the tunnel alignment passes under the AT&N Railroad and the access road to the Alabama Dry Dock and Shipbuilding Company Yard. Both the road and railroad had to be relocated during the construction of the East Ventilation Building.
We were required to maintain as much clearance over the tunnel at the bulkhead lines as exists over Bankhead Tunnel. These criteria together with having to meet the highway grades of elevation 15.0 on the west and elevation 18.0 on the east, established the grades in the tunnel as 5.25 percent on the west and 5.05 percent on the east.

**Floated-in-Place Tubes.**

The Contractor sublet the fabrication of the steel shells of the tubes to the Alabama Dry Dock and Shipbuilding Co. which is located about a mile or less from the construction site. The double shells are fabricated on side-launching shipways. Two tube sections have been launched to date. The steel shells are provided with temporary bulkheads at each end to keep them afloat. They are moved to an outfitting berth where the reinforcing steel is tied in place and the electric conduit and other utilities are put in place. The concrete is poured in accordance with a strict schedule. Both the tremie, or ballast, and the strength concrete are poured by this schedule to maintain a uniform floatation and to keep the hogging and sagging moments within acceptable limits. The tube section will have all its strength concrete and most of its tremie concrete in place before it leaves the outfitting berth and will have approximately one-foot free board when it is moved over the previously prepared trench into which it will be sunk. The trench will be two feet, or more, deeper than the location of tube bottom. Precast concrete slabs will be placed in the trench at the location of the ends of the tubes, on which the tubes can rest and from which adjustments can be made.

**Channel Clearances.**

The presently authorized depth of the Mobile River Channel is 40 feet plus two of overdredging below M.S.L. over a width of 600 feet in the section crossed by the tunnel. M.L.W. is 0.80 feet below M.S.L. The decision was made to place the top of the tunnel at a minimum of five feet below the overdredging line. To provide some tolerance over the minimum the top of the tunnel was set at 48.8 feet below M.S.L. at the west edge of the channel. The top of the tunnel will be 52.5 feet below M.S.L. at the east edge of channel.

It is planned that the most easterly tube will be sunk first by adding additional tremie concrete and proceeding westerly until all tubes are in place.

The tubes are aligned and connected and the outside sealed with tremie concrete. The temporary bulkheads are removed beginning at the east end, and each joint completed by welding the waterproofing plate, placing the strength concrete with all the necessary appurtenances encased. When this procedure is complete the roadway slab at the joints will be completed. Then the big finishing job starts, with the placing of roadway curbs, setting tile,
and placing railing. Also, pulling electric cable and wire, placing lights, safety devices and communications system. The mechanical and electrical equipment which goes into the ventilation buildings will be installed while the tubes are being completed, and brick placed on the ramp walls. The asphaltic concrete roadway surface will be one of the last items installed. Many very interesting features have been omitted and others have been curtailed because of time and space limitations.

Figure 6. Picture inside a tube showing the strength ring reinforcing steel in place, the air-ducts tied in place along each side and invert portion of concrete strength ring.