Light Rail Transit Tracks in Pavement

ROBERT E. CLEMONS

One of the important features of light rail transit (LRT) is the ability to locate tracks in downtown streets and transit malls, thus eliminating the high capital cost of grade-separated aerial structures or subways. The designs of transit tracks in pavement have evolved over the past 100 years in domestic streetcar systems. This paper traces this evolution by looking back at the initial streetcar track designs, by reviewing the development of heavy streetcar tracks, and finally by reviewing the track details and costs of seven recent North American LRT projects. Comparison of these seven projects shows a wide variation in design criteria and a resultant cost range of $67 to $270 per single-track feet. The conclusion is that much work remains to be done to establish cost-effective design criteria for transit track in pavement.

THE FIRST PRACTICAL STREET railway in the United States was opened for service 100 years ago, in February 1888, by Frank Sprague in Richmond, Virginia. The system consisted of 12 mi of track, 40 vehicles with two $7^1/_2$-hp nose-mounted traction motors, a 500-volt dc overhead wire distribution system, and underrunning pole trolley, and included an 8 percent grade. So successful was this project that within 3 years 200 street railway systems were in operation or on order.

Track designs for these early systems were based on steam railroad technology modified to allow installation of paving stones above the crossties as shown in Figure 1.

Typical track of this era was subject to rapid deterioration because of inadequate funding, poor drainage, low-quality materials, deferred maintenance, and the pavement covering the track. The more successful properties developed the deeper girder rails that eliminated the need for rail chairs,

Bechtel Civil Inc., P.O. Box 3965, San Francisco, Calif. 94119.

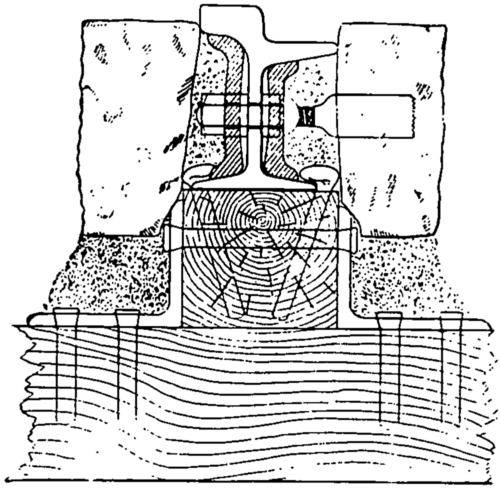


FIGURE 1 Track construction circa 1892.

increased the vertical bending strength, and provided a uniform flangeway. Increased streetcar weight and speed and increased weight and speed of trucks that also operated on the trackway led to the concrete encasement of the timber or steel crossties, and eventually the entire track structure. An example of a heavier streetcar track design is shown in Figure 2.

LIGHT RAIL TRANSIT TRACK

Today's light rail transit (LRT) track has evolved from yesterday's streetcar track, adapting to a wide range of new technical and aesthetic requirements. The keystone, however, remains cost-effective design. Today's light rail philosophy is the same as yesterday's: the minimum design for the expected service. Other important features are as follows:

- Flexibility—changes over the project life to accommodate changes in demands or patterns;
- Low maintenance—always the goal to achieve a balance between capital cost and annual expenses;
- Capacity increase—by increasing speed, size, and weight of vehicles, utilizing exclusive or semiexclusive trackways, and implementing progressive or preemptive traffic control systems;
- Stray current control—to electrically isolate the running rails from underground facilities and utilities;

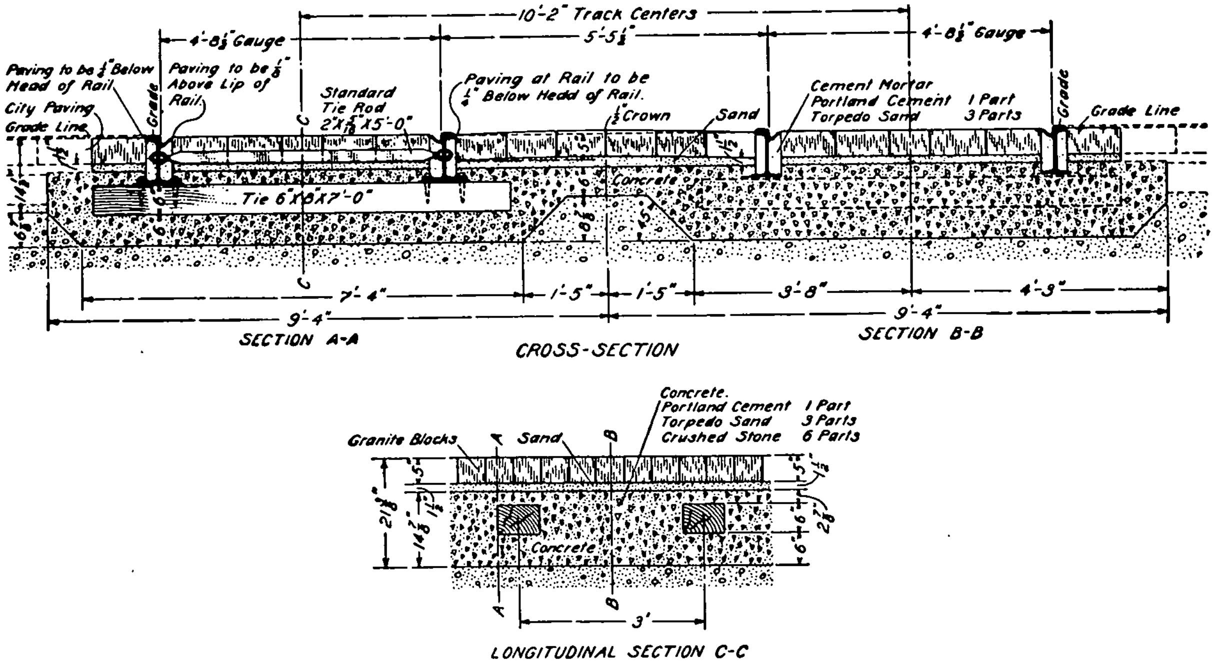


FIGURE 2 Paved truck design for heavy streetcars circa 1915.

• Ground vibration damping—to isolate the track structure from adjacent buildings;

• Urban design—both the location and appearance of the tracks to contribute to the environment.

LIGHT RAIL PROJECTS

Tables 1 and 2 presents general data for seven light rail projects that include paved-type track. More detailed information is presented in the following sections for each project; detailed cross sections are included.

TABLE 1 GENERAL DATA FOR LIGHT RAIL PROJECTS IN SAN FRANCISCO, CALGARY, AND SAN DIEGO

	San Francisco	Calgary	San Diego
Contract no.	MR642	–	LRT11
Cost ($ millions)	–	–	3.7
Bid date	1977	7/79	11/79
Service date	–	6/81	7/81
Single track (mi)	1.0	2.4	3.1
Rail section	104ER	Ri60	90RAA
Cost date	–	6/80	6/80

TABLE 2 GENERAL DATA FOR LIGHT RAIL PROJECTS IN BUFFALO, PORTLAND, SAN JOSE, AND SACRAMENTO

	Buffalo	Portland	San Jose	Sacramento
Contract no.	1Z0081	LS-4B	Mall	85-02
Cost ($ millions)	16.9	20.8	29.3	12.1
Bid date	10/81	5/84	2/85	4/85
Service date	10/85	8/86	12/87	9/86
Single track (mi)	2.5	2.2	0.5	–
Rail section	128RE	Ri59	Ri59	115RE
Cost date	2/83	2/85	6/86	1/86

Cost Comparisons

Bid price comparisons for six projects are summarized in Table 3. The total price per single-track foot varies from $66.52 to $269.87. It must be noted that some of the costs presented are not strictly comparable in terms of escalation or breakdown. However, the trend toward more complex and costly paved track is very apparent.

TABLE 3 BID COST COMPARISON

Item	Description	$ U.S. per Single Track-Foot					
		Calgary	San Diego	Buffalo	Portland	San Jose	Sacramento
Owner-Furnished Material							
1	Rail	(19)	15.00	27.11	19.52	19.52	18.21
2	Crossties	A	7.50	A	A	A	7.84
3	OTM	A	3.75	A	A	A	3.75
4	Tie bars	(19)	A	(6)	1.49	A	A
5	Total	(19)	26.25	27.11	21.01	19.52	29.80
Contract Work							
6	Install track	(19)	25.56	140.00	18.00	135.00	20.00
7	Rail welds	(19)	5.24	(6)	10.67	(6)	7.50
8	Ballast	A	6.76	A	A	A	8.08
9	Track slab	B	A	49.15	15.12	(6)	A
10	Base course	A	A	?	2.42	(6)	A
11	Filter fabric	A	A	A	A	A	1.33
12	Rail elastomer	(19)	A	(6)	168.00	A	A
13	Tie bar coating	(19)	A	A	2.80	A	A
14	Insulating membrane	(19)	A	(6)	A	(6)	A
15	Pavement	B	B	(6)	B	B	B
16	Reinforcing	B	B	16.57	B	B	B
17	Mobilization	(19)	2.71	7.54	31.85	18.16	?
18	Total	(19)	40.26	213.26	248.86	153.16	36.91
19	Grand total	223.58[a]	66.52	240.37	269.87	172.68	66.71

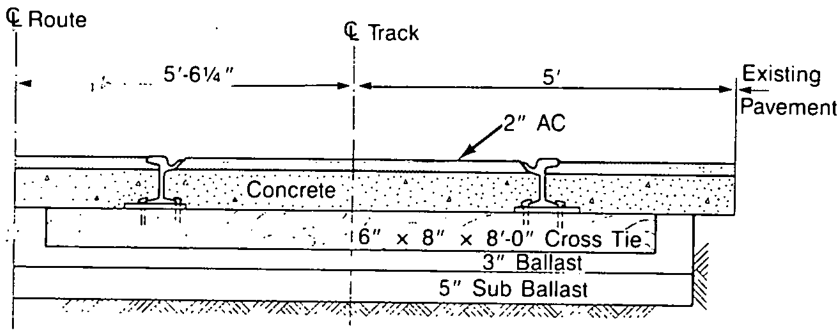
NOTE: (*X*) = cost included in item *X*. A = not required in design. B = cost excluded.

[a]Converted at the rate of $1 Can. = $0.868 U.S. ($1700 Can./route meter) [0.868/(3.3 × 2)] = $223.58 U.S./track foot.

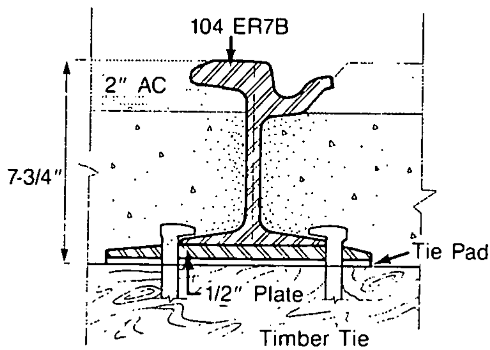
San Francisco Paved Track

The paved track design of the San Francisco Municipal Railway is typical of the many streetcar systems that flourished prior to World War II. This design was used when Municipal Railway's surface tracks in West Portal Avenue were reconstructed in 1977.

The paved track consists of 104 ER7B girder rail with the plates and pads spiked to treated crossties spaced at 24 in. on center as shown in Figure 3. The crossties are supported in compacted ballast level with the top of the crosstie. The rails were then thermite welded into continuous strings. Non-reinforced concrete is placed over the crossties and up to 2 in. below the top



Paved Track Section



Rail Detail

FIGURE 3 Paved track design, San Francisco.

of the rail. Asphaltic-concrete (AC) pavement material is then installed level with the top of the rail.

The track was reconstructed in a center trench while two-way traffic was maintained on West Portal Avenue and on all cross streets. Comparable cost information for this track is not available.

Calgary Paved Track

The Seventh Avenue Transit Mall is the downtown surface portion of Calgary Transit's C-Train Light Rail Project. The double-track transit mall is located on Seventh Avenue S.W. from Third Street S.E. to the terminal station near Ninth Street S.W. The mall contains approximately 12,700 single-track ft of paved track. Construction of the mall began in July 1979 and revenue service on the system began in June 1981.

The paved track consists of two-track reinforced track slab placed on 2 in. of styrofoam insulation as shown in Figure 4. The Ri-60 girder rails were sandblasted and coated with polyurethane off-site, and then thermite welded into one-block lengths and connected with coated gauge rods. After blocking and wedging to line and profile, a two-component polyurethane elastomer was poured under and around the rail base to anchor the rail to the track slab and to provide resilient support of the rails. A full-depth concrete pavement was placed with a slot for each rail. Expansion joint sheet was installed on the sides of the slots, and the slot was filled with concrete and capped with an asphalt seal. Electrical insulation for stray currents was provided by the 20-mil polyethylene sheet on the top of the track slab and the 30-mil polyurethane coating of rails and tie bars.

The mall construction was done in two seasons. The work was completed one block at a time so an entire section of Seventh Street would not be out of service for an entire construction season.

The track costs shown in Table 3 were furnished by Calgary Transit staff without breakdown. The cost is an average per unit length, including design, procurement, construction, and construction management of the girder rails, gauge rods, polyurethane coatings and elastomeric pads, polyethylene sheets, expansion joint material, and special trackwork; but excludes civil and utility works, track slab, and pavement.

San Diego Paved Track

The City Centre Contract LRT-11 is the downtown segment of the San Diego Light Rail Guideway Project of the Metropolitan Transit Development Board. The double paved tracks are located in C Street from the Amtrak

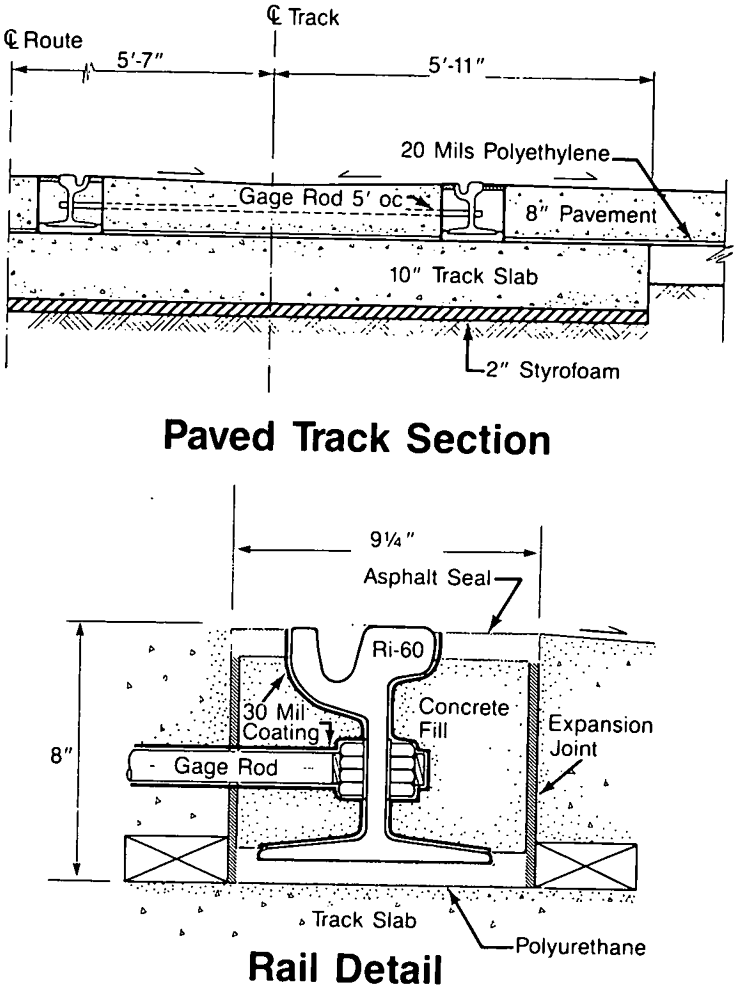


FIGURE 4 Paved track design, Calgary.

Station to 12th Avenue and on 12th Avenue from C Street to Commercial Street. This segment contains 15,886 single track ft of paved track and 418 of curved paved track with braces and guard rail, excluding special trackwork units. The pavement in the exclusive trackway is asphaltic concrete except at cross streets where concrete pavement is used to accommodate the heavy traffic. Bids to construct the City Centre contract were opened in November 1979. Construction was completed within 190 working days, and revenue service began in July 1981.

The paved track consists of conventional timber crossties in rock ballast supporting 90 RA welded tee rail as shown in Figure 5. The crossties are treated softwood spaced 24 in. on center. The plates are American Railway Engineering Association (AREA) plan 2, and the rail anchors are True Temper boxed on every other crosstie. The ballast is AREA #4 gradation, 6 in. deep under the crosstie and placed on compacted subgrade. The 25-m rails were thermite welded in place to form continuous welded rail. Flangeways were formed when the AC pavement was placed.

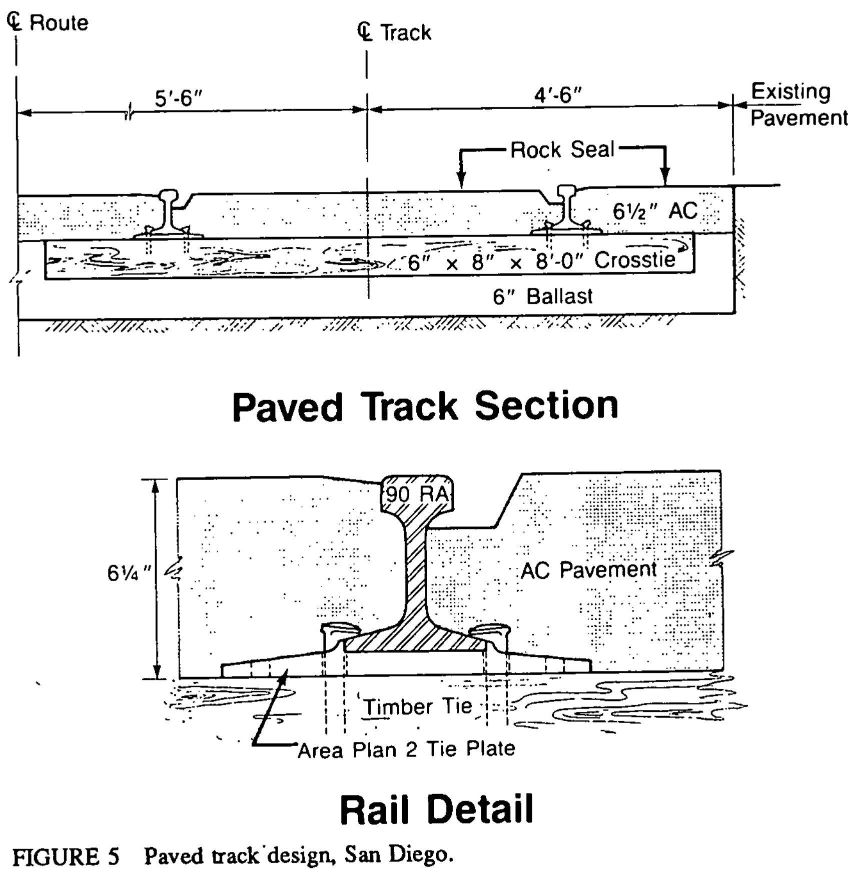


FIGURE 5 Paved track design, San Diego.

Cross traffic at each intersection was maintained as well as pedestrian movements and access to all buildings.

The track costs shown in Table 3 are based on an evaluation of bid costs and the plans and specifications for the contract. The rail, crossties, and other track materials (OTM) were all furnished by the owner, and the costs are calculated from the delivered contract prices. The item to install paved track includes the cost to store and install all owner-furnished materials and to furnish and install insulated rail joints. Separate costs are listed to furnish and install rail thermite welds and ballast. Mobilization cost is an allocation of that bid item for the paved track installation. The paved track costs do not include excavation, site work, pavement and other steelwork, utility relocations, or electrical connections and ducts.

Buffalo Mall Track

The Buffalo Mall is the downtown surface portion of the Buffalo Light Rail Rapid Transit Project of the Niagara Frontier Transportation Authority. The double-track transit mall is located on Main Street between South Park Avenue and Tupper Street at the subway portal. All mall track is installed under contract 170081, which includes 10,827 single-track ft of standard mall track as shown in Figure 6 and 2,334 single-track ft of continuous floating slab mall track. Bids for contract 170081 were opened October 6, 1981. The contract was awarded for $16.94 million and all work was completed within 730 calendar days. Revenue service began in April 1985.

Standard mall track consists of a nonreinforced concrete slab that supports 128 RE-7A girder rails held to gauge by threaded rods through the rail webs. A nominal 3-in.-thick leveling course of epoxy-modified grout supports the rails to the design profile. The track slab is poured on compacted select backfill. Vibration damping is provided by a continuous $^3/_{16}$-in.-thick elastomer pad under the base of rail. A $^1/_{16}$-in.-thick layer of rubberized asphalt over the base of rail, grout leveling pad, and top of the track slab provides a permanent, flexible, monolithic water and moisture barrier. The contractor elected to electric weld the girder rail into strings approximately 700 ft long and thermite weld the strings together in the field.

After installation to line, profile, and gauge, the track was anchored against thermal movement by placing large concrete weights on the rails. The rails were field welded. The first step in pavement installation was the filling of all volume below a line $5^1/_2$ in. below the top of the rail with a hot-mix roller-compacted asphalt fill material. The pavement is a $5^1/_2$-in.-thick reinforced concrete layer poured on the asphalt fill and around the girder rails.

Construction scheduling required most of the standard mall track to be substantially completed within 216 calendar days from site availability. Main Street was closed to vehicular traffic for the duration of the mall track construction. Two-way traffic on all cross streets was maintained on at least half of each intersection.

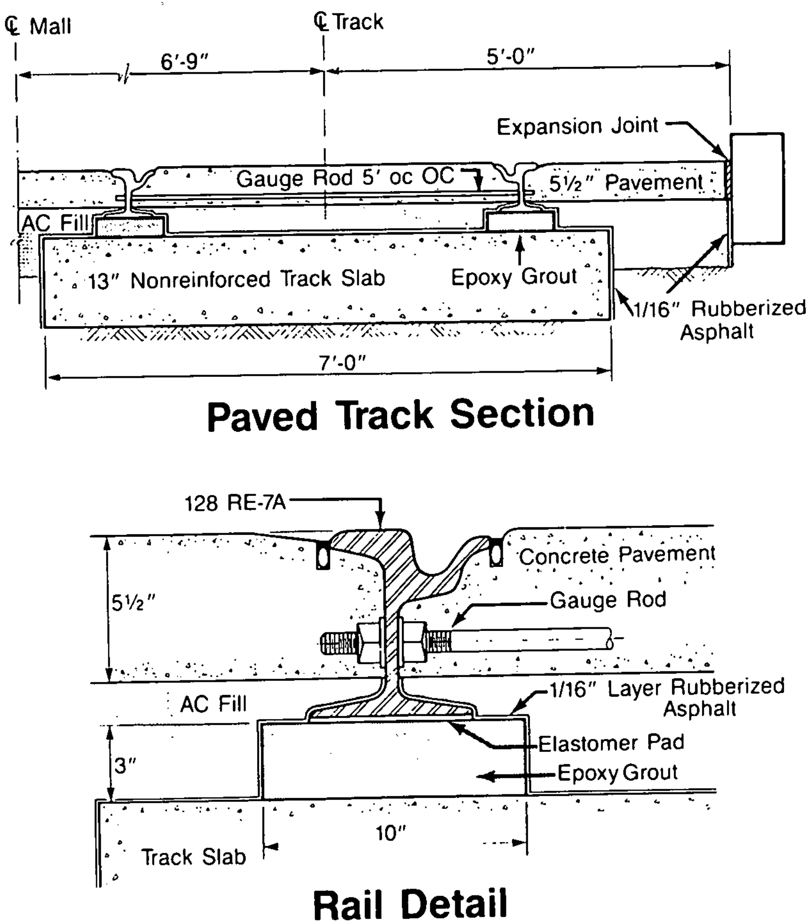


FIGURE 6 Paved track design, Buffalo.

The track costs shown in Table 3 are based on an evaluation of bid costs and the plans and specifications for the contract. The 128 RE-TA girder rail was furnished by the owner. Contract costs are based on the pay item to install track, which includes all costs to furnish and install the grout leveling course, continuous elastomer pad and adhesive, rubberized asphalt material, asphalt fill material, gauge rods, concrete pavement, rail welds and joints; and to install the owner-furnished girder rail. The cost per foot of track slab is calculated from the pay item for a cubic yard of track slab concrete. The reinforcing cost is based on an assumed amount of steel in the concrete pavement. Mobilization cost includes an allocated amount of the items for mobilization maintenance of traffic, and engineer's facility.

Costs excluded from Table 3 include initial street excavation and subgrade preparation, utility relocation, special trackwork units, continuous floating slab mall track, granite curbs and the street improvements outside the track zone, and all drainage facilities within the track zone.

Portland Downtown Track

Line Section LS-4B is the downtown segment of the Banfield Light Rail Project of the Tri-County Metropolitan Transportation District (Tri-Met) of Oregon. All tracks are embedded in street pavements and are located on N.W. First Street from N.W. Everest Street at the foot of the steel bridge approach to S.W. Morrison Street. There the tracks divide onto the one-way couplet formed by S.W. Morrison Street (northwest bound) and S.W. Yamhill Street (southeast bound) to the downtown terminal at 11th Street. This segment contains 11,823 single-track ft of paved track excluding the special trackwork units. The pavement in the track zone is Belgian blocks with limited amounts of concrete pavers, brick, and poured concrete. The paved track design and configuration are the same for all types of pavement. Bids to construct line section LS-4B were opened on May 17, 1984, with construction scheduled to begin in June 1984 and to be completed in November 1985. Total low bid for the contract was $20.76 million. Revenue service actually began in September 1986.

The paved track consists of a reinforced-concrete slab that supports Ri-59 girder rails held to gauge by tie bars as shown in Figure 7. The concrete slab is supported by a 4-in. layer of aggregate base over a compacted subgrade. Electrical isolation and vibration damping are provided by fully encasing the girder rails and the bars in a poured polyurethane elastomeric material. All surfaces of the rails and tie bars, and the top of the track slab, were cleaned and primed to ensure a bond with the polyurethane to maintain proper alignment and electric isolation. The two-component polyurethane materials were pumped and mixed in automatic equipment and placed in the rail slots formed by the previously installed pavement materials. Since the chemical set of polyurethane is sensitive to water, heat blowers and tents were used during installation to eliminate all moisture. The 25-m-long rails were thermite welded after installation to eliminate weaker bolted joints and reduce the electrical resistance in the traction power return circuit.

Construction scheduling included specified access and completion dates for each city block of the project. During this period, all traffic was removed from that block except for emergency vehicles. A specified number of lanes of cross traffic was maintained at each intersection. Pedestrian movement and access to all buildings were maintained throughout the project.

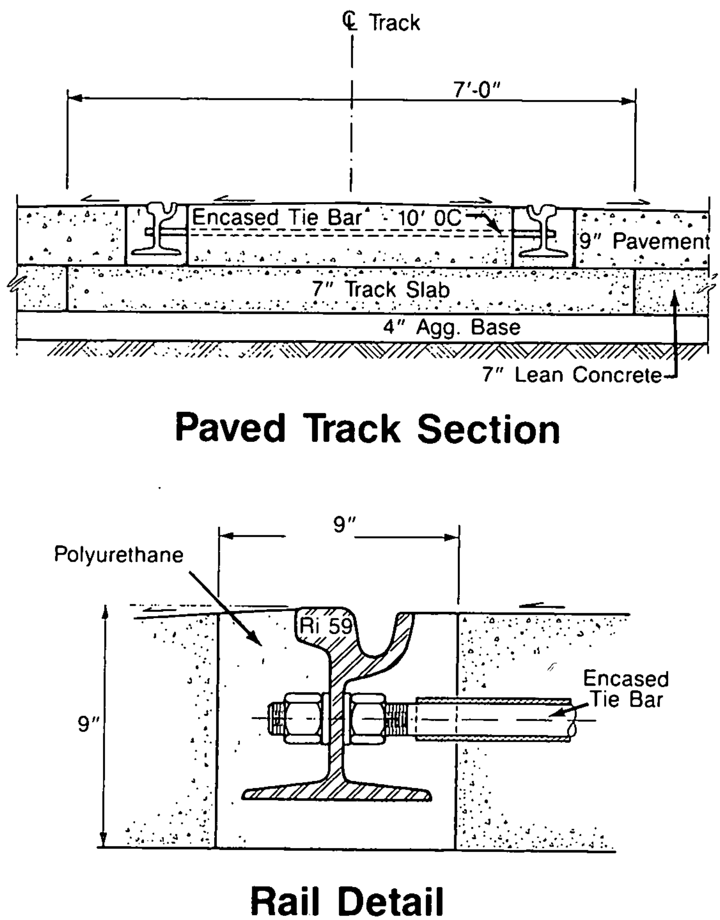


FIGURE 7 Paved track design, Portland.

The contract specifications required the contractor to perform low-voltage track-to-earth electrical resistance tests during and after track construction. Completed sections of double track (four rails with electrical crossbonding) were required to have a resistance of at least 100 ohms per 1,000 route ft. This seems to be the first time that the acceptance of railroad or transit track was based on electrical resistance testing. The tests were very useful in determining short circuits to ground. Although all accepted sections of track tested above the minimum resistance, the test results varied so widely that it was impossible to calculate an average resistance for this track design.

The track costs shown in Table 3 are based on an evaluation of bid costs and the plans and specifications for the contract. The Ri-59 girder rail and tie bars were furnished by the owner. Contract costs are based on pay items to install track and to furnish and install rail welds, track slab, aggregate base course, polyurethane rail elastomer, and polyurethane coating of tie bar. Mobilization costs include an allocation of bid items for mobilization, traffic control, signs, and flagmen. Costs not included in Table 3 are the excavation of the track trench, preparation of subgrade, relation of utilities, all pavement and street work, all special trackwork units, and all miscellaneous trackwork items such as track drains, electric boxes, and wheel stops.

San Jose Transit Mall Track

The San Jose Transit Mall is the downtown portion of the Guadalupe Corridor Light Rail Project of the Santa Clara County Transportation Agency. The transit mall is located on First Street (southbound) and Second Street (northbound) between San Carlos Street and St. James Street. The mall contains two types of embedded track:

- Type A—Mall track, 4,499 track ft. The top of the concrete track slab is depressed 4½ in. below the top of the rail to allow installation of granite pavers.
- Type B—Mall track within street right-of-way, 1,770 track ft. The concrete track slab extends up to the top of the rail to form the pavement surface (see Figure 8).

Bids to construct the mall track were opened on February 7, 1985, and revenue service began in December 1987.

Both types of mall track consist of a reinforced-concrete track slab with slots for the installation of Ri-59 girder rail. The slab is supported by a 4-in. layer of asphaltic concrete. Noise and vibration isolation are provided by ½-in.-thick closed-cell neoprene panel installed vertically between the side of the track slab and the adjacent concrete pavement. Electric isolation is provided by a 100-mil-thick dielectric barrier of geotextile fabric and multiple polyethylene sheets under and up the side of the track slab. The Ri-59 rail is clamped down to embedded anchor bolts and steel plate, and the rail slot is filled with lean concrete.

Track costs shown in Table 3 are based on an evaluation of bid costs and the plans and specifications for the contract. The Ri-59 girder rail was furnished by the owner at a unit cost assumed equal to the cost that Portland paid the same supplier in 1984. The single-track-foot bid cost for mall track

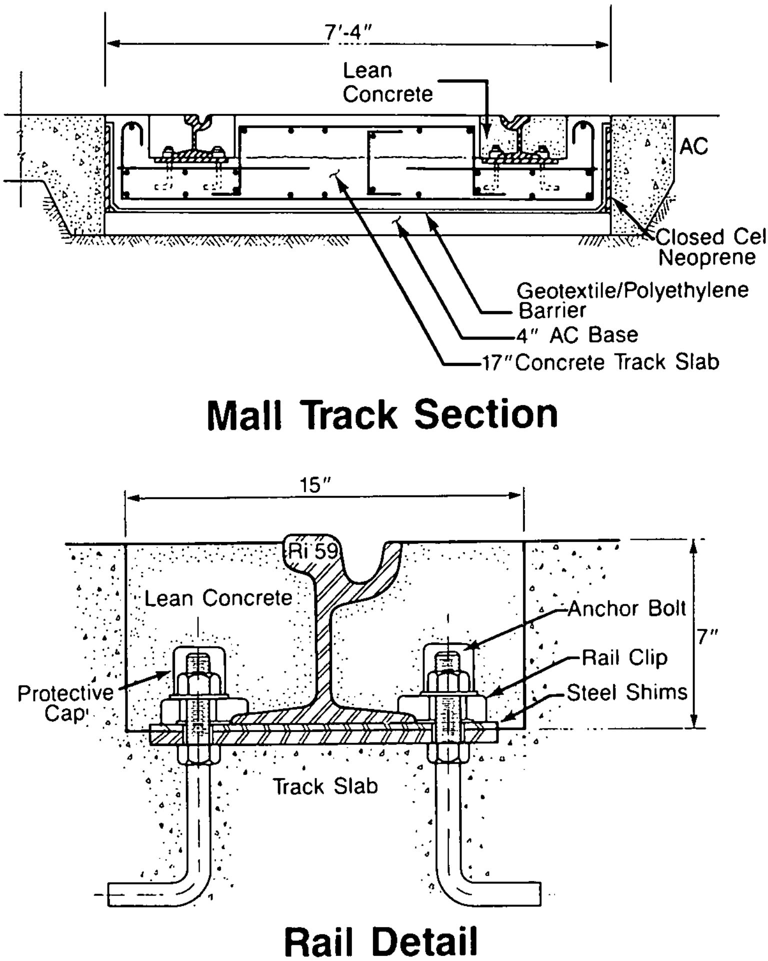


FIGURE 8 Paved track design, San Jose.

varied from $135 for Type A to $285 for Type B. These costs include subgrade preparation; furnishing and installing aggregate base, AC base, track slab, noise and vibration isolation panels, electric isolation barrier, lean concrete, and rail clamps; and installation of owner-furnished rail, including welds and crossbonds. The costs shown on Table 3 are for Type A without the granite pavers. Mobilization costs of $18.16 per track foot include allocations of bid items for general cost and right-of-way and traffic control.

Sacramento Mall Track

Contract 85-02 contained all the paved track in Central Sacramento of the RT Metro of Sacramento Regional Transit District. The double paved tracks are generally located on 12th Street, the K Street Mall, the Seventh and Eighth Street one-way couplet, and the O Street Mall. Bids on Contract 85-02 were opened on April 9, 1985. Subsequently, this contract was divided and rebid as two smaller contracts.

The K Street Mall paved track consists of conventional timber crossties in rock ballast supporting 115 RE welded tee rail as shown in Figure 9. The crossties are treated softwood spaced at 24 in. on center. The tie plates used are AREA plan 7. Ballast to a minimum depth of 8 in. under the crosstie is placed directly on a compacted subgrade reinforced with a filter fabric. The

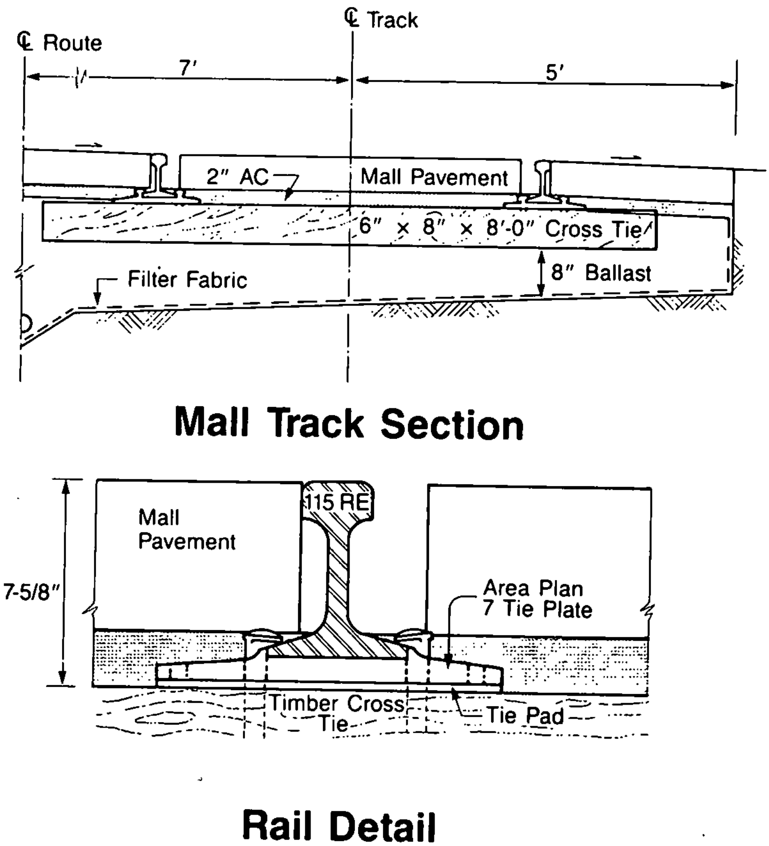


FIGURE 9 Paved track design, Sacramento.

rails were thermite welded in place to form continuous welded rail. Flangeways were formed in the mall pavement.

The track costs shown in Table 3 were furnished directly by Sacramento staff. OTM costs were assumed equal to those in San Diego.

CONCLUSION

The design of track in pavement has evolved in many different directions over the past century. These seven projects reflect some of these differences and a wide range in the initial track costs. The principal reason for these differences is the criteria established by each property for its track. Some properties demand minimum initial cost, while others are willing to spend more to build paved track to reduce annual maintenance expenses or to achieve electrical insulation and vibration damping properties.

This paper is a start in the process of determining the long-term benefits of these seven designs and developing cost-effective design criteria for future LRT track in pavement. The development of such criteria is a long-term research project—a worthwhile one that deserves the support of TRB or the American Public Transit Association.