URBAN RAIL
TRACK STRUCTURES
Program Digest

U.S. Department of Transportation
Urban Mass Transportation Administration

NOTICE

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U.S. DEPARTMENT OF TRANSPORTATION
Urban Mass Transportation Administration

Contents

1. History

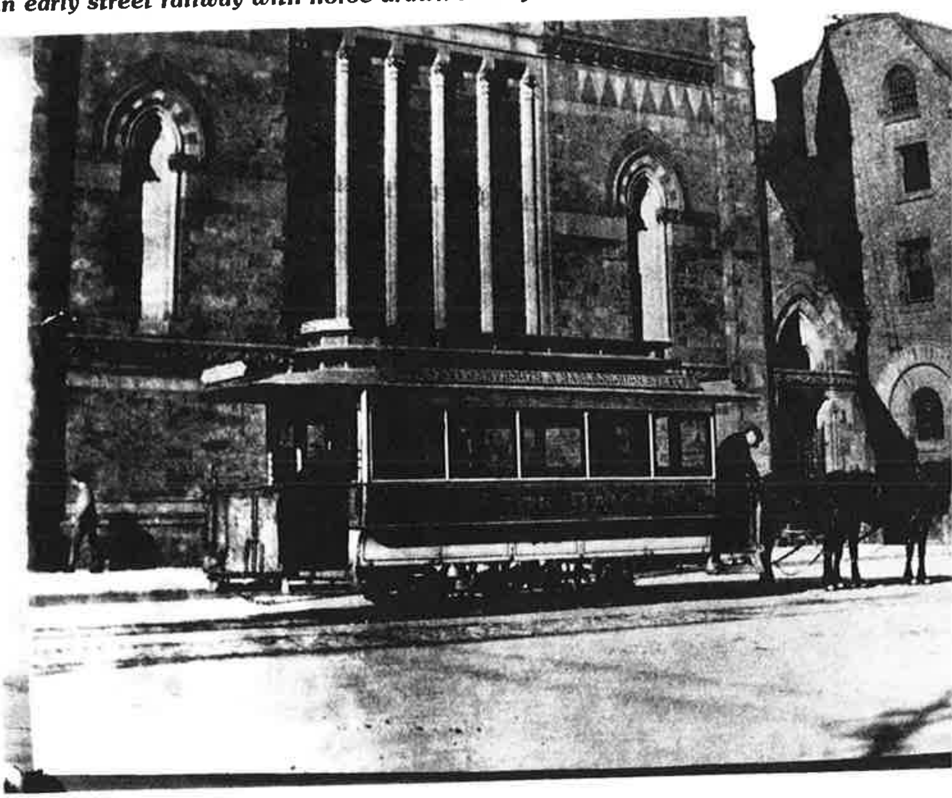
Today's urban transit systems trace their origins to November of 1832, when the country's first horse-powered rail line opened in New York City. The line was less than a mile long and offered service along New York's Bowery. In the following fifty years, the United States street railway industry grew to include 3,000 miles of track, operated by over 400 street railway companies.

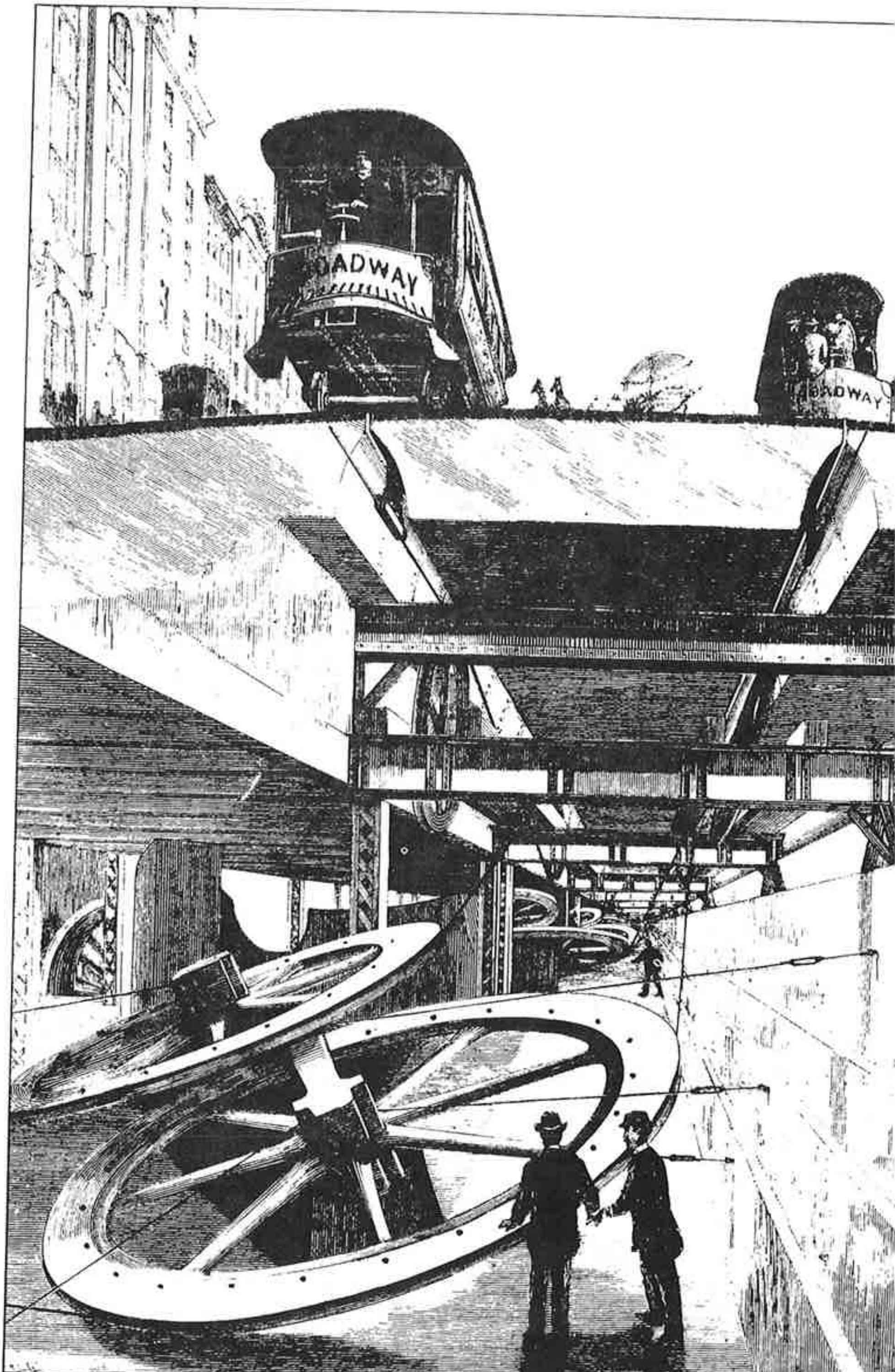
Early street railway lines, such as the one in New York, were built as urban extensions of the growing intercity rail network. Expanding city populations created the need for transportation systems which could move city dwellers to and from places of employment as well as meet their other urban transportation needs.

The horse-powered rail syste
railroad technology wherever possi
wheels on guiding rails being an ea
The similarities between urban rail a
both in purpose and technology,
recognized by rail entrepreneurs w
obtain rights-of-way on city streets.
sensing pre-emption of city street
freight service quickly passed laws
ferent track gages for urban systems
ing up a barrier to the extension of
over city streets.

While solving one problem,
brought about another; differing
the urban rail systems throughout
These differences, still existing,
major stumbling block to the sta
vehicles, and other urban rail ele
could potentially provide cost,
other important benefits to urban
operators and their cities.

An early street railway with horse-drawn trolley car.





Artist's conception of an early cable-car transit system.

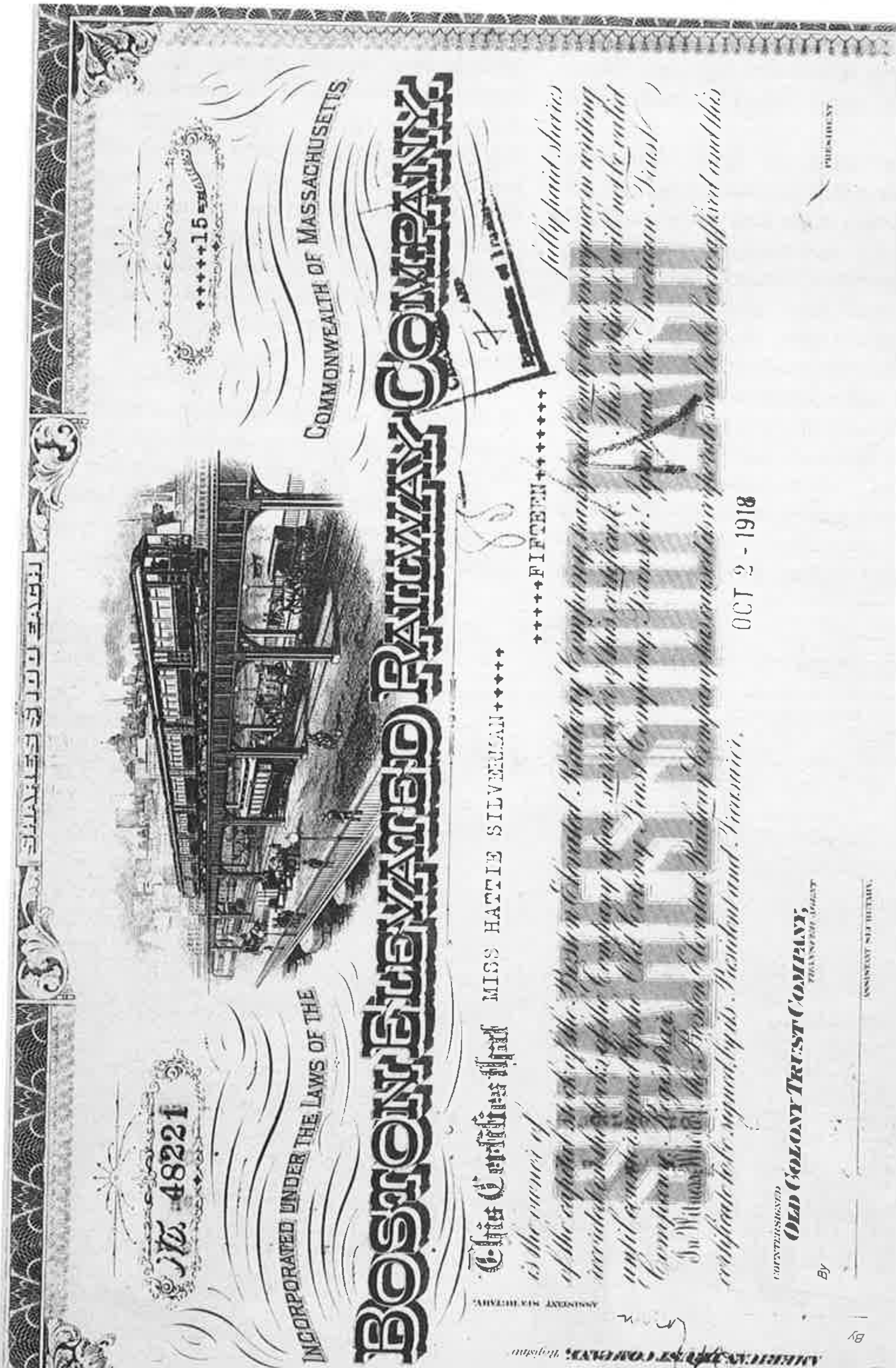
Motive power for early urban rail transit was supplied by horses, and the vehicles were forced to compete for street space with pedestrians as well as other horse-drawn conveyances. Urban railways, perforce, were limited to small, single vehicles.

Large cities, such as New York and Chicago, expanded their urban rail systems until they could no longer cope with congestion and traffic demand. To surmount these problems, transit system operators created tracks over the streets on elevated steel structures, running trains of multiple cars pulled by steam "locomotives". To control costs and to manage within confined city environments, small cars, lightweight track and structures, and rails supported by timber ties were used.

Pollution and operating costs of both steam engines and horses grew increasingly intolerable with swelling city populations. Fortunately, during the late 19th Century, electricity became a practicable power source for vehicle
Transit operators were quick to ada
propulsion technology to urban ra
gaining extra benefit because the
could be used as part of the electrica
viding power to the vehicles. Elec
brought operating costs into line an
pollution problem at one stroke. It
the door to better service, higher c
reduced costs. Equally important wa
tial it brought of operating underg
resulting subways provided high lev
transit service while avoiding, an
tributing to, city street congestion.

Today, skyrocketing constructi
to reverse the move to underground
Instead, new transit lines are more
on the surface. The new lines som
railroad surface rights-of-way an
operate on elevated structures o
street, expressway or railroad right

Labor intensive, early track maintenance.



SHARES $100 EACH
No. 48221
+++++15+++++
INCORPORATED UNDER THE LAWS OF THE COMMONWEALTH OF MASSACHUSETTS
BOSTON ELEVATED RAILWAY COMPANY.
This Certifies that MISS HATTIE SILVERMAN+++++
+++++FIFTEEN+++++
fully paid shares
OCT 9 - 1918
OLD COLONY TRUST COMPANY,
TRANSFER AGENT
ASSISTANT SECRETARY.
PRESIDENT

The same skyrocketing costs are also encouraging better system upgrading and maintenance throughout the urban transit industry. The term "permanent way" is used by the British railway engineers to define the track and its supporting structure. Unfortunately, track is not as permanent a way as the engineers and operators would like it to be. Rail lasts perhaps 20 years and ties up to 50 years, while fasteners are expected to last up to 25 years. In addition to the costs of these, related maintenance costs total over 80 million dollars annually.

Riders are made aware of the cost of running a public transit system every time they put fares in the turnstile or pay tax bills. Maintenance, including trackwork, is a significant part of that cost. Successful measures to prolong the life of the track components and structure can reduce the impact on the user's pocketbook, and that of the community as a whole.

The future, with high-cost, tight energy supplies and larger urban populations, will place heavy, new demands on the Country's urban transportation system. Urban rail has come a long way from its beginnings. However, much must yet be done in the development and application of modern technology to meet the changing demands and needs of our society for fast, dependable, comfortable, safe and economic urban public transportation.

The United States Department of Transportation Urban Mass Transportation Administration (UMTA) is charged with assisting in the attainment of improved urban transit systems and is specifically interested in track technology research and development for three major reasons:

1. Urban transit systems generally do not have the resources needed either to study the causes of, or to develop the solutions to, track structure problems.
2. The private sector has been generally unwilling to invest in transit R&D because there is a relatively small market for new technology, no guarantee that an innovative technology would be purchased, and little likelihood of a reasonable return on
3. Transit systems, funded federal, state, regional, governments, are a cruci resource which must be pres tected, and improved.

To assist urban rail planners ar in developing and using the most c track technology possible, UMTA h ed the Track Technology Program. in the transit industry, organizatior makes it difficult to solve problems from the interaction of moving vehic facilities. Using a multi-disciplinary break down some of those institutic UMTA is working to solve vehicl blems. Efforts by various teams wor technology, vehicle technology, abatement are directed and coo UMTA to produce information for t transit industry, its consultants and

A further aim of the program age common solutions to comm and common needs. The resulting will conserve and optimize the efforts and funds, contribute to the economies of scale, concentrate r aggregated demand becomes an dustrial market, and make for a interchangeability of equipment, within and among transit systems.

The Department of Transpo portation Systems Center (TS UMTA by conducting the Track Program and providing guidance assistance to assure that its results a able for transit industry use in imp tions and reducing costs.

This Program Digest describe track structures used in urban rail and the directions being take supported projects to solve associ and to develop improved tr elements.

2. Existing U.S. Rail Transit Track

Track Inventory

The UMTA study, **U.S. Transit Track Assessment and Research Needs** (9)[*], published in December 1979 reports on a survey of rapid rail transit track in the U.S. The survey was based upon questionnaires sent to all rail transit properties and on extensive interviews and workshop sessions involving industry representatives and American Public Transportation Association staff.

The track inventory disclosed that in 1979 there were 1341 single track miles in revenue operation, 188 miles under construction, and 139 miles planned. While not large in comparison with the total mileage of intercity railroad track in passenger and freight service, this track is used intensively, and is responsible for the safe and efficient transport of approximately 4.5 million people each day. Table 1, taken from this study, shows how this mileage is distributed among different types of track environment and construction. Of all track now in operation, approximately one-fourth is at-grade, one-fourth elevated, and one-half underground. Once all the track under construction or being planned is added to existing track, the proportion of at-grade will increase to 30 percent, elevated will remain at 26 percent, and underground will decrease to 44 percent. Of all track now in operation, slightly less than half (47 percent) is conventional tie and ballast (crushed rock) construction, and approximately one-third of the total mileage is continuous welded rail (CWR).

Approximately three-fourths (78 percent) of all rail now in use has a weight of 100 lb. per yard or less. Virtually all track now in construction or planned will be welded and, for the most part, will use rail weighing 115 lb-per-yard.

Track Condition

This same study included d
tions of 52 sample sections of tr
the condition and geometrical
the track. Using that data, the
was then evaluated with respec
qualities:

- Smoothness—which aff
ride quality
- Durability—which affects
quality in the immediate
- Maintainability—which af
ride quality over the long

The rating system used a
one hundred, with ratings belo
to be unsatisfactory. A relatively
all track was found to be fair t
large portion was considered to b
good or better. On the whole,
track exceeded federal track safe
speed-related classifications, as
city railroads. However, the tran
not afford to be overly satisfied w
this evaluation because much
being deferred and track
deteriorating.

Admittedly, the cost of keepi
at an acceptable level is high bec
ficulty of working in tunnels, on
tures, and even on at-grade
However, track does deteriorate
needs repair or replacement. D
tenance as well as normal aging
result in the need for substantial
track and structure repair. At that
be opportunities for upgrading
employing improved componen
nology so that future maintenance
will be less, ride quality will be
there will be less undesirable no
deleterious effects.

[*] See Bibliography at end of this Program Digest.

TABLE 1
TRANSIT TRACK SUMMARY

Track and Structure	In Operation	In Design or Construction
	Miles of Single Track	
Subway or Tunnel		
Concrete Slab	378.9	68.7
Ballasted	257.3	0.6
Surface, Ballasted		
Concrete Ties	95.2	18.6
Wood Ties	186.2	41.2
Elevated		
Embankment, Concrete Ties	—	1.7
Embankment, Wood Ties	69.7	—
Open Structure	257.6	—
Concrete Slab	56.2	56.5
Ballast on Concrete	27.0	—
Bridge	12.7	0.4
TOTAL (rounded)	1341	187

Source: Reference 9

Track in serious need of maintenance attention.

3. Transit Track

Track structures consist of rails, supporting elements, and a fastening system which secures the rails to the supporting elements. Track structures are built on the ground (at-grade), in tunnels (underground), and on elevated structures such as bridges and overpasses (above-grade). The primary functions are to provide cost-effective guidance and resilient support to vehicle wheels and to properly distribute wheel loads to the roadbed. In addition, the structure must offer minimum resistance to train movement, thus minimizing vehicle propulsion power requirements.

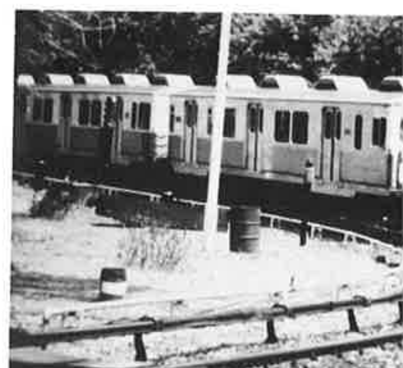
The rails of the composite track structure, in conjunction with an insulated "third-rail" or an overhead wire (catenary), also serve as electrical conductors through which the power for a vehicle's traction motor flows. In many cases, the rails are also used as elements of the electrical circuits for signals, train control or train communications.

The traditional track support system uses ties in a crushed rock bed called ballast, or ties attached to a substructure such as a bridge. In recent years, track has been supported on continuous support systems, such as concrete slabs, without the use of ties.

The track structure must be able to withstand the forces—vertical, lateral and longitudinal—arising from the passage of a train. These forces are imposed through wheel/rail contact and arise because of the mass and velocity of the train and from train acceleration and decelerations. Additional forces can be introduced by temperature changes if the rail is continuous welded.

Urban transit rail exists in a severe environment. Static wheel loads generated on transit systems may not be as great as those of intercity rail systems but the number of vehicle passages over a given time is high, curves are sharper and grades steeper, resulting in relatively high lateral loads and high lateral-to-vertical (L/V) load ratios. Thus, while intercity rail suffers failures

Tie and ballast track with pow[...] rails.



Train rounding a sharp curve o[...] restraining rail.

due to stress fatigue, urban rail is s[...] wear rates. Other urban rail opera[...] contribute to this process — traffic [...] essentially one-way, and a variety o[...] particularly ones with a relatively hig[...] of unsprung mass, produce a[...] amount of wear.

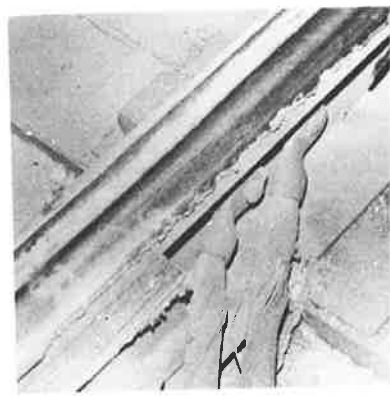
Urban systems are also forced to use sharp curves in the congested city environment. Curves of 100-foot radius are found in Boston and Chicago, and, even in the modern Washington Metro, there are curves of 700 to 900-foot radius. Frequent traffic on such sharp curves generates high lateral forces and severe rail wear. Certain sharp curves on some systems receive such wear that the rail must be replaced several times a year—a process which is difficult, expensive, and can be service-disrupting, especially in underground and elevated locales.

Studies (6) have reported that lateral forces on curved track can be two to three times higher than those on tangent (straight) track while vertical forces are about the same in both cases. These measurements were taken on curves which are considered relatively gentle by transit standards. In one instance, the lateral forces on tangent track, which were about 10 percent of the vertical load, increased by a factor of 2½ on curved track. Other investigations on curves on the Washington Metro found lateral forces almost as large as vertical forces. Track irregularities or excessive speed could increase lateral loads even further, causing even more damaging wear.

Lateral forces, and in particular the lateral-to-vertical force ratio (also known as the derailment quotient) must be kept low to reduce the possibility of derailments. The problem is one of controling vehicle-track interactions and requires complementary, mutual efforts by both track and vehicle designers. Proper track design is important, but the vehicles must also be "easy" on the track.

Different track structure elements are subject to different types and degrees of wear. Bending caused by vertical or lateral forces from passing trains causes fatigue in rails and fasteners. The rail head takes the most severe punishment—since the wheel/rail area of contact is relatively small, the stresses are very high, and the metal is embrittled and therefore subject to cracking or flaking away. Wheel slide, both flange and tread, grinds away rail surfaces. It also contributes to flat wheels which have further detrimental effects on the rail. Mechanical wear, and corrosion encouraged by weathering and atmospheric pollution, can be partic rail joints where the rail ends are passing wheels.

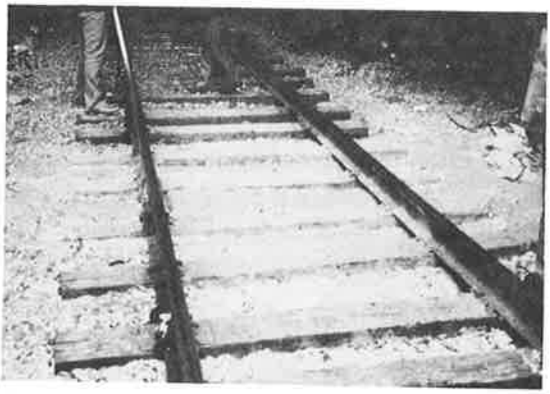
The rails of electrified track ar to electrolytic corrosion. During the street railways, the importance o the low resistance of the rail retu not recognized. In many installatio electrical path bypassed the rails, g to ground and then in and out o and cables, removing metal by ele along the way. This was not only the rails but also for the other m the path. It was so bad that Cincin forbidding the use of track as a circ their street railway system.



Rail showing effects of electroly

Other elements of the rail f are also exposed to mechanical and weathering. Timber ties, attacked from all sides. Early i railroad and transit track, rai directly to the ties, which had be As loads increased, tie plates spread the vertical load over a la accept the lateral load and spre number of spikes. At the same the tie was being crushed by t stones were digging into the b entire tie was rotting away.

Normally, the ballast struc by intrusion of finer material fro which works its way into the ba resiliency and ability to drain away water. However, ballast is also subject to mechanical wear because the ballast particles move as they are compacted by passing loads. As a result, serious degradation of ballast can be found even where it is used on bridge decks and on rock-bottomed tunnels where there is no resilient subgrade.



Timber ties showing signs of deterioration.

Track structures not using conventional tie and ballast construction are also subject to wear, both from the passage of tra weathering. Many of these instal resiliency of normal tie and balla the rails and fastening componer ject to large stresses which can ult failure, and costly replacement.

The Transit Riders' Viewpoint

Urban transit riders want d safe service at acceptable cost. wit of comfort and convenience. The and vehicles, as an interactive syst jor role in the need to meet these

Ride quality is an important user's total reaction to the syster rider often has to stand and mo train as it enters or leaves a statio particularly vulnerable to excessi roll, which, at a minimum, can a his comfort and well being. An ex ride can upset the user and shake

A busy subway station.

in the safety and reliability of the system. In extreme cases, it can result in personal injury.

Ride quality is influenced by the basic geometry of the track—horizontal and vertical alinement of the rails (the degree of deviation of the actual track from its designed location), and more importantly, the physical relationship between one segment of track and another as the train moves along the line. The rate-of-change of horizontal and vertical alinement of the rails is critical to the perceived ride quality. As speed increases, abrupt changes in track curvature or surface profile become more apparent as a rough ride. The vehicle suspension system can cope with irregularities up to a point but beyond that, discomfort increases, and in extreme cases, safety can be threatened.

Urban rail systems are designed to operate in confined and congested urban areas. In general, sharper curves are requ steeper grades. Also, acceleration deceleration tend to be greater to m headways. As a result, to provid levels of service and ride quality, tenance must be superior.

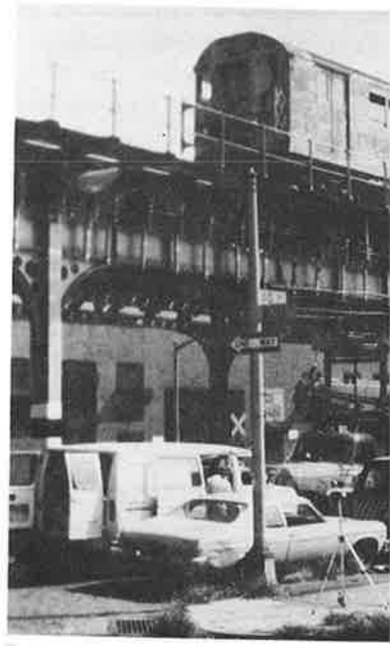
Track can be a significant fa erating unpleasant and uncomforta trains and in stations. The public older systems is often characterize word—"noisy". Impact noise from irregularities, other noise generate scale imperfections of the rail an faces, and, worst of all, the intense squeal on sharp curves, are all par rail noise that patrons must endure. be both airborne and ground-transm be annoying, perhaps injurious, to destructive to property.

Track in city streets can require tight curves and special (girder) rail.

Impact, roar, and squeal can be even more of a nuisance to the neighbor of an urban rail line than to its users. While placing the tracks underground or behind barriers can eliminate airborne noise problems, vibration generated at the wheel/rail interface and transmitted through the soil into structures can still be a disturbing element.

People can learn to live with some transit system noise, and have done so in many cases with older systems. However, it is not a happy situation and any change in noise level, either higher or lower, can bring angry reactions from the public. Thus, introduction of new rolling stock, or track components, can change noise levels and thereby create problems.

Noise can be alleviated through proper design, and visitors to a new, modern system often remark on its quietness as compared to older transit lines.



Track structures in urban areas source of excessive noise and vib

Maintenance of transit track is still highly labor intensive, lacking specialized equi

Transit riders are also sensitive to travel time. Permanent speed restrictions on curves or grades are sometimes unavoidable because of physical constraints in congested urban areas, but they do increase transit time. Changing the basic geometry of older systems to avoid such slow-downs is virtually impossible in many cases.

Delays to service resulting from frequent repairs of failed track components reduce riders' confidence in the day-to-day reliability of the system. The rider can also be seriously affected by extended service shutdowns, restrictions on operating hours, or diversions of service needed for major track replacement or improvement projects.

Efficient and highly mechanized track renewal equipment, designed specifically for intercity rail use where space constraints usually do not exist, is not generally adaptable to urban transit systems. Unfortunately, the urban transit mark been large enough to warrant the dev its own maintenance equipment.

Direct Environmental

In the case of surface rail lines light rail lines in city streets, the tr can have a noticeable visual impa ments, elevated structures and oper as other urban rail tansit structures, eyesores. An irregular, unkempt, right-of-way can be a detriment to t ity. On the other hand, a properly reconstructed, or new track structu well-distributed ballast, good draina designed fences, barriers and lan be non-detracting and perhaps ev addition to the urban scene.

4. Track Types and Problems

Rapid transit track can be categorized by its location—at grade, underground, or on elevated structures.

While the basic track structure, made up of rails and supporting elements, may be similar for all three locations, the detailed design and the way the components perform can be very different for each location. Methods of construction and maintenance can vary considerably with location because of supporting substructure differences and because of the influences of temperature variations and degree of exposure to the weather.

A track fastener or some other element of the track structure may perform well in a subway environment, but fail when used outside. A track structure comprised of wooden ties laid in crushed rock (ballast) may have satisfactory characteristics for attenuation of vibration when used at grade but perform poorly in an underground structure. It is essential, therefore, that a track component or a track system be analyzed in relation to its location.

This section describes the track structures in each of the three basic categories, as well as their particular advantages and disadvantages. However, there are many elements and problems common to all types and these, for simplicity of presentation and avoidance of redundancy, are treated under At-Grade Systems.

At-Grade Systems

While at-grade track comprises only about one-fourth of all urban heavy rail rapid transit track at present, this proportion will rise in the future due to the high cost of constructing underground and elevated structures, and the expansion of at-grade light rail systems.

Subgrade

Early railroad builders qu
aware of the problems of tra
Various materials, as well as size
rail supports were tried with var
success. Better track structures ev
with increased awareness of the
providing proper subgrade and d
railroad practice was, and still is,
experience and the "cut-and-try
design. The 1974 UMTA report "
Design Tools and Criteria for Urb
Structures" (2) stated that, even t
much still to be learned about th
construction of the subgrade, and
with ballast and track. Fortunat
rarely catastrophic, but an unstabl
quires constant attention, calling
track raising and lining operations

New roadbed embankments s
uniform rate of settlement as differ
ride quality deterioration. The
recommends that adequate infor
borings and other methods of soil
be acquired to aid design and cons
grade track. Selection of proper fill
good control and inspection procedu
that fill is properly placed and comp
essential to the achievement of a g

Drainage

It has been said that good
depends on three things: drainag
and drainage. While incorporati
drainage into the track substruct
straightforward in new work, it is n
easy in track rehabilitation or recons
jects. Where right-of-way width
conventional open drainage ditche
Where space is tight, as it often is
systems, closed drainage consisting
pipe below or adjacent to the tra
used. Access for cleaning these dra
tant. Retaining walls, or other protec
are sometimes needed to prevent m

adjacent areas from washing onto the right-of-way and fouling the ballast and drains.

Drainage work can be a significant cost item in the major rehabilitation of at-grade track structures. Although short-term benefits can be gained by replacing or refurbishing only the rails, ties, and ballast, neglect of subgrade and drainage problems can cause the need for frequent resurfacing of the track and premature replacement of track components.

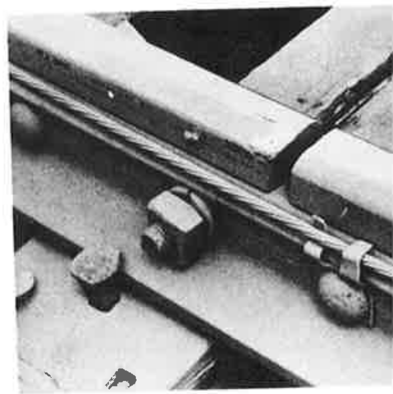
A common problem with at-grade track is the flow or "pumping" of fine material from the subgrade into the ballast. This intrusion can impair the drainage capacity of the ballast and thus its resilient support of the track. Loss of subgrade material also creates low spots in the track. In recent years, "engineering fabrics", or mats of non-woven fibers, have been used to reduce the severity of material flow problems. These mats are placed between the ballast and the subgrade, acting as a wick to lead water away and also as a filter to keep fine soil particles from entering and clogging the ballast. There is some question about the effective lifetime of these fabrics, and research is needed on this subject.

Ballast has received considerable attention in UMTA-funded studies. The 1974 UMTA study reported on various procedures used for determining ballast pressure under the tie and at the surface of the subgrade. These procedures considered depth of ballast, tie area and spacing, and loading. A follow-up study entitled *Pilot Study for Definition of Track Component Load Environments of 1981* (6), reported on the extensive ballast field measurement program conducted at the Transportation Test Center in Pueblo, Colorado. Load and deflection measurements were made of rails, fasteners, ties, ballast and subgrade for the purpose of finding more cost-effective ways of designing dependable track structure.

Ties

Approximately 73 percent of existing at-grade transit track is constructed with timber ties. The remaining track is built with concrete ties. There is a trend toward the use of concrete ties, and, when lines now planned or un[...] tion are added, the proportion of ti[...] fall to around 70 percent.

In recent years the quality of ti[...] decreased. Ties are no longe[...] seasoned and therefore pressure tr[...] perservative chemicals is not as effe[...] years ago. Ties drying in service s[...] quently, requiring increased use o[...] devices. It is anticipated that s[...] wooden ties will continue to dec[...] transit systems also face the fact t[...] small market compared with inter[...]



Battering of rail joints by whe[...] track problems.

To obtain ties economically, they [...] on intercity railroad maintena[...] which, through their volume of c[...] price of ties down for transit prop[...] themselves.

Concrete ties are common[...] roads and transit systems in Eu[...] places where good, inexpensiv[...] available. Proponents of concret[...] concrete ties have a longer [...] strength than wood, and are e[...] distribute loads to the ballast [...] manner. Additionally, fewer c[...] needed to carry the same load, t[...] number of rail fasteners needed [...] track installation and tamping.

Concrete ties are heavier [...] making them more difficult to h[...]

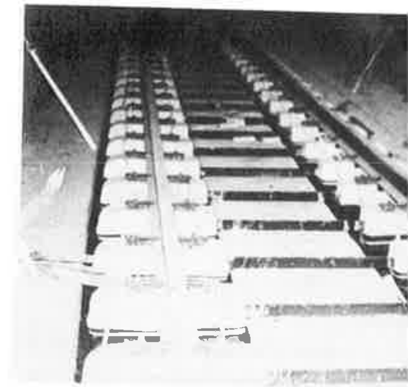
this weight also creates a more stable track, particularly in the lateral direction, which is important for resisting the thermal stress characteristic of continuous welded rail (CWR).

To assist the urban rail transit industry, UMTA has participated in programs to test various configurations of concrete ties and fasteners, and has developed a preliminary specification for a standard concrete tie and fastener for transit track (7). The goal is to promote standardization within the industry, so that economies of mass production can help the costs of concrete ties.

Concrete ties are produced in two basic configurations: mono-block and duo-block. Mono-block ties are normally prestressed, thus improving load carrying capability and durability. Duo-block ties are often made of two conventionally reinforced blocks of concrete, tied together by a steel structural shape. Both configurations were tested as part of the UMTA program in the laboratory and in the field, and are

Monoblock concrete ties come in various shapes and employ many different fastening systems.

covered by the Preliminary Specification (7). Both configurations could be used with any of several fastening systems, thus promoting competition among suppliers. Standard ties can be used by systems having different track gages and sizes of rail, because the tie manufacturer can provide adjustable supports for fastener inserts embedded in the ties.



Duo-block concrete ties are incre with slab track to limit vibration.

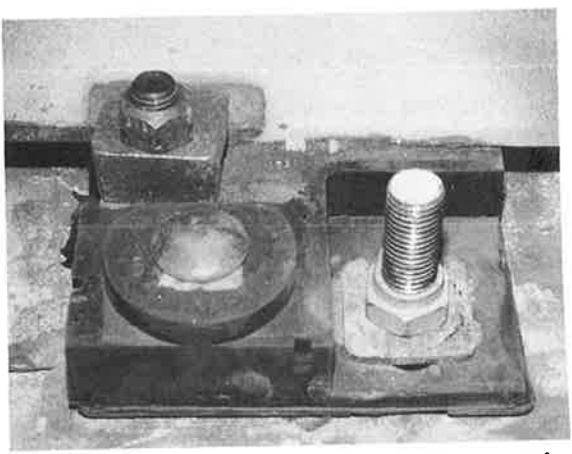
An important detail in the de crete ties and associated rail fastene vision of electrical isolation betweer required in order to use the rail as circuit element. Non-conducting ela and plastic insulators provide this is pads also serve as a cushion betweer tie, reducing mechanical wear and tie from high frequency mechanical

Ties are also called upon to third rail, restraining rails, guard rai track appurtenances as well as the rails. This means that additional in choring devices have to be embed crete ties when they are fabricatec some of such planning problems, tin often intermixed with concrete ties posite track design to support track s crossings, and to handle other specia because they can be modified on sit nately, wood and concrete ties do n same dynamic response characteristic fore do not combine to provide a arrangement.

Fastening Systems

The traditional fastener system fc is the cut (driven) spike and tie plate. hold the tie plate and rail secure aga movement. Some transit systems spikes instead of driven spikes. Both types allow the rail to move longitudinally and consequently, in continuous welded rail, anchors are attached to the rail to restrain longitudinal movement. The longitudinal forces result from acceleration or braking of the train, and from thermal stresses arising when the continuous welded rail is subjected to temperature changes. When rails are replaced, the rail-holding spikes must be removed and replaced, to the detriment of tie life.

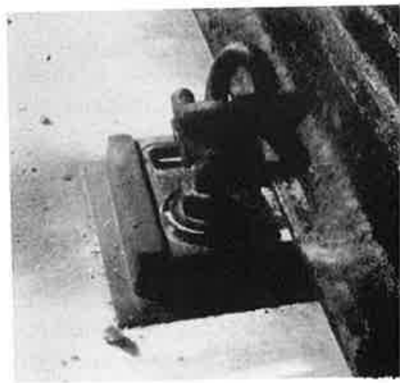
Europeans have led in the development of fastening systems which permanently anchor the tie plate to the tie, and provide separate fasteners to attach the rail to the plate. Normally these fasteners are designed to clamp the rail to the plate with enough force so that separate rail anchors are not needed. Some fasteners use a spring clip held in place with a bolt, while others use a spring clip held by a fixed insert, to clamp the rail without a bolt. The latter have the advantage of fewer parts and speedy, consistent application and removal, but are not easily adjustable.



Direct fixation fastener as installed on the Washington Metro.

Both fastener types are used with concrete ties. However, the tie plate is not needed with concrete, so that fastener clips and/or bolts are attached to shoulders or inserts built into the tie. This eliminates the need for separate rail anchors with concrete ties. Insulators are needed, however, to electrically isolate the rail from the ground.

An UMTA test program has ga
data on the various fastening syste
wood and concrete ties. Guided
work, load environment data is cu
collected in field tests to give the
the tie and fastener suppliers a be
the actual track environment.



Direct fixation fasteners can us
to hold the rail, such as this ela

Rail

For years the length of a ra
United States was limited to 39
of the standard railroad gon
recently have mills begun pro
rails. Long ago, steel, repla
wrought iron, vastly improved t
durability of rail. More recently
has been improved by use of he
hardened, alloy steel that is
curved track where mechanical

The street railways very ea
arc welding to repair joints and
thermite process. In the late 193
welding machines were develop
ing became more attractive due
and more consistent weld qua
welding plants have been set
and some transit systems ha
welded by these facilities, altho
of rail are not, in general, easily
sit agencies. A more commo
welding makes use of porta
equipment, and the rails are

The UMTA-sponsored urban rail track inventory and assessment (9) showed that about one-third of the rail now in use on urban rail systems is welded rail. This proportion will increase since virtually all new track will be welded in the future.

While rail welding is accepted practice now, there are problems needing further study. Work is being done under Federal Railroad Administration sponsorship, some of which is applicable to urban systems, but more work is needed specific to urban transit rail. One area needing attention is the joining of the special alloy rails with each other, and with the standard control cooled rail—processes that have sometimes resulted in excessive weld failures. Another problem area concerns welding rail at ambient temperature extremes. Because of schedule constraints, urban rail systems often have to install track when temperatures are very low or very high. However, long, welded-rail segments should be anchored and field welded at mid-range ambient temperatures so that they do not shrink excessively in the winter and pull apart at a weld or expand excessively in the summer and buckle. Methods to ensure reliable and long-life welds under all temperature conditions need study and development.

Various UMTA studies have investigated the weight (or size) of rail suitable for urban rail use. Table 2 shows the rail sizes now in use, both jointed and welded, on all U.S. urban rail systems. It excludes light rail systems which are either standard rail section or girder rail, the latter in pavement. When rapid transit lines now under construction or planned are completed, the length of track will grow by over 300 miles, and most of this will use 115 pound rail.

The UMTA studies have indicated that relatively lighter rail sections such as 85 pound and 100 pound, can easily handle transit vehicle loads. However, other considerations often govern the choice of rail section. Heavier sections in long, welded lengths will better resist buckling, and will distribute wheel loads over more ties and subgrade, thus helping to keep maintenance costs low. Larger rail sections can also carry electrical return curr electrical loss.

TABLE 2
RAIL BY WEIGHT
AND JOINT TYPE

Rail (Pounds/Yard)	Lengtl (M
	Jointed
85	13.2
90	71.6
100	791.3
112	—
115	12.8
119	8.0
130	2.0
132	—
Total	898.9

Source: Reference 9

At-Grade Slab Track

Problems of maintaining typ track have led engineers to seek a nent track structure. Concrete sl been tested in a number of countrie intercity rail track at grade. Typica ventional ties and ballast are replace crete slab. In a few cases, precast c

At-grade slab track test section Island Railroad.

have been used instead of cast-in-place concrete. The slabs have been formed by conventional means, or by a modified, highway slip-form paving machine.

The quality of the subgrade and drainage is very critical for concrete slabs. In fact, if the subgrade fails, allowing excessive settlement of the track slabs, repair work to restore the track surface is more difficult than with conventional tie and ballast track.

The rail fasteners used with at-grade slab track can be similar either to those fasteners used with concrete ties, or to the more complex, direct fixation fasteners used on modern elevated structures and in subways.

Slab track is much more costly to construct than tie and ballast track—up to two to three times the cost. However, in the 1981 UMTA study on slab track (8) it was found that, under certain cost assumptions, the life cycle cost of slab track could be less than that for tie and ballast track because of reduced maintenance costs. Most slab track installations have been in foreign countries and have been experimental in nature.

There have been only two applications of at-grade slab track in the United States. A 1.1 mile section of double-track slab track was installed in 1980 on a grade separation project on the Long Island Railroad. Also, a number of short sections of slab track were installed in Atlanta, mostly in stations or at transitions between at-grade and elevated or subway track. No long-term performance information is yet available.

An interesting aspect of slab track is that, compared to conventional tie and ballast track, the large mass decreases ground vibration, but the absence of sound-absorbing ballast results in increased airborne noise.

Elevated Systems

Most older urban rail elevated track and support structures now in service have a strong resemblance to elevated track found on intercity railroad bridges and viaducts. Thus, the techniques of supporting and fastening the rails for urban transit and for railroad are similar,

Elevated structure on the Washin

Modern elevated structure in Sa

Open-deck elevated structure u and adjacent wooden ties for ad against derailment.

although the supporting structures are different. Most railroad bridges are relatively short crossings of other transportation facilities or of rivers. On the other hand, most urban rail elevated structures are relatively long and, in most cases, are directly above a parallelling street or railroad.

The typical older urban rail elevated structure is the open deck type which has timber ties fastened directly to steel bridge girders. Another type of older elevated structure, which is also used on intercity railroads, is the ballast deck structure. Here, tie and ballast track is supported by a solid bridge deck resting on bridge girders of various configurations. The newer urban rail structures have departed considerably from these traditional forms by using direct fixation construction in which the rails are secured directly to a concrete deck slab. The deck slab may be supported by, or integral to, the structural girders.

There are 353 single-track miles of urban rail on elevated structure, of which 258 miles (73%) are on open deck structure, 27 miles (8%) are on tie and ballast structure, 56 miles (16%) are on direct fixation construction and 12 miles (3%) are of other methods of construction. In the future, when lines currently under construction, or planned, are complete, the total single-track miles will increase to 443, with virtually all the new track of direct fixation construction, increasing its proportion of the total to 33%.

Open Deck Construction

In the past, the open deck structure was the simplest, lowest cost type of construction. The typical structure is comprised of longitudinal steel girders, usually directly below, or just outside of the rails. Timber ties, often at closer spacing than used with at-grade track, rest on the top flange of the longitudinal girders. Rails rest on top of the ties. A longitudinal, heavy-timber guard is fastened to the top of each end of the ties, parallel to the rails. Other longitudinal timbers, or conventional rails, are placed to the inside of each running rail. The longitudinal members act as guard rails to keep a deraile[d]
structure.

The installation of timber ti[es]
elevated, open-deck structures is
The job is superelevated, "banke[d]
parlance, and the girders are lev[el]
tually every tie has to be custom m[ade]
ment of ties anywhere on an eleva[ted]
difficult and costly. It is usually m[ore]
replace segments of track in pane[ls]
making local, isolated replacemen[t]

Welded rail is not generally u[sed]
deck elevated structures. This is be[cause]
rail must be firmly fixed to the ties
not expand or contract independ[ently]
thermal stresses. As a result, exc[essive]
rail forces are generated which cann[ot]
by most open-deck elevated structu[res]
such problems, jointed rail is used
pand and contract because of the g[aps]
rail ends. Unfortunately, this solves
at the expense of another—transit
ing over the joints generate much
noise. Study and development
track structures are necessary to p
approaches to these problems than

Ballast-Deck Structures

Timber tie and ballast-deck st[ructures]
mally employ jointed rail constructi[on]
there is 6 to 8 inches of ballast un[der]
The older elevated structures and
modern, short, ballast-deck bridg[es]
have a concrete slab resting on stee[l]
ported by steel girders in various co[nfigurations]

The track on ballast-deck struct[ures]
to maintain than than on open-dec[k]
Special ties are not needed and
ballast tamping methods can be use[d]
or other structural elements next
provide good restraint against lateral
However, these elements on a ballas[t]
ture make it impossible to insert or
from the side. Tie replacement is con[ducted]
efficiently, therefore, by replacing
track or by other methods where rail
and all or most of the ties are replac[ed]

Ballast-deck structures are less noisy than open-deck structures; perhaps 5 to 10 db quieter in terms of maximum noise levels. The timber ties and ballast absorb some of the vibration, and the concrete deck and steel structures needed to support the heavy track bed absorb more. As a result, ballast-deck structures radiate little noise.

Direct Fixation Elevated Track

Urban system designers have found that by eliminating the conventional tie and ballast support system on an elevated structure, the height and dead weight of the structure and also the cost can be reduced. In this approach, the concrete deck acts as part of the basic girder structure. WMATA, MARTA and Miami have implemented a variety of these new structural systems and they have proven successful in operation so far.

A key to the success of these modern elevated structures is the direct fixation rail fastening system. This system secures the rail to the structure, and provides both electrical insulation and vibration isolation between rail and structure. In general, welded rail is used and the lack of joints means less noise generation. Most of the direct fixation track is in subways, so the track fastener issue will be discussed at length in the section on underground track. However, one aspect of

Direct fixation fasteners on an elevated structure.

direct fixation fastener design applie
to elevated structures. This concern
ing, thermal-induced stresses, and
the structure with respect to the ra

The girders and supporting co
designed to handle expected loads
them to the foundations. Howeve
the new structures use welde
fasteners must transmit vertical,
and lateral forces generated by
and longitudinal forces resulting
stress, from the rail to the deck.
girder structure also expands and
temperature variation and the fas
must also reconcile the rail
movements in order to avoid
stresses in the rails.

One solution is to clamp the
the deck in that position of the st
thermal movement is relatively
ends of the girders, where movem
large, the clamps are loose, allov
ture to move without stretching
the rail excessively. The precis
means of doing this is the subject
debate. Many installations use ste
bolted to the base plate. These f
two types—one clamps the rail ti
allows movement in one directi
term success of this approach d
ting the right fastener in the right
ting proper bolt tension. The r
labor needed to accomplish this
come by. In addition, it is not
corrosion, or rust, will affect the
formance of the "loose" clamps.

The Hong Kong Metro uses
approach. The supporting girde
single element, continuous ove
spans. The structure is anchore
and can move a considerable
ends as the temperature cha
points, a sliding joint is used so
mily clamped to the deck at all p
ple robust, fastening system, c
the deck moves. The problem
is that the rail slip joints are ex
and require careful maintenanc

Underground Track

There are 636 single track miles of underground heavy rail rapid transit track in the United States. Of this, 257 miles or nearly 50 percent use tie and ballast track, and the balance use a wide variety of direct fixation slab methods. When lines now under construction or in planning are complete, the total length of underground track will be 717 miles, of which about 64 percent will be direct fixation slab track.

Underground Tie and Ballast Track

The earliest United States subways were in Boston and New York and began operations around the turn of the century, using conventional tie and ballast track. The major difference between underground and at-grade tie and ballast construction is the presence of the concrete floor or "invert" slab used in underground tunnels. The invert slab is usually sloped to the side or center of the tunnel, where small drainage channels are provided. In some cases, instead of a channel, a pipe is buried in the slab with drain openings at frequent intervals. When tie and ballast track is used underground with an invert, the need to distribute the load is greatly reduced; the ballast layer under the ties can be relatively thin, 4 to 8 inches, instead of the 8 to 12 inches for at-grade track.

While ballast in underground structures is not subject to some of the environmental influences affecting at-grade ballast such as heavy rain, freeze and thaw cycles, or intrusions of fine material from the subgrade, it still can be degraded over a period of time. As the ballast "works" under pressure from passing trains, it can break down, adding additional fine material to the dust and other small particles settling in the tunnel. The ballast contaminants accumulate over a long period of time and, in effect, form a "cement" so that the ballast no longer provides a uniform, resilient support for the track.

Most of the underground tie and ballast track uses timber ties. These can easily be obtained in a variety of thicknesses and lengths, and can be cut on the job to fit special invert condi-

tions. Because weathering is
underground than that experienc
or elevated track, treated timber t
a long time, unless they are "spike
quent rail replacement. The use
permanently attached to the tie, w
spring clips for securing the rail,
less of a problem.

Concrete ties, occasionally us
ground urban rail track, offer hea
durability. However, concrete tie
deeper than timber ties, which red
imum allowable ballast depth u
assuming that the top-of-rail prof
vertical clearance requirements.
problem can also limit the applica
crete ties when it is desirable to re
rail with heavier, higher rail section
crete ties do have certain limitatio
the reconstruction of older systems

Modern underground constructi employs direct fixation track.

While most new underground track will include the use of direct fixation fasteners, there are still many existing miles (257) of underground tie and ballast track that will have to be maintained and upgraded. Maintenance of tie and ballast track in underground structures is not easy — work and storage space is very limited, and tunnels are dark and dirty places to work. Changing ties is difficult, primarily due to restricted side space; spot replacement requires 3 or 4 ties to be moved to get at one bad one. This extra work has made panel track, or similar approaches to tie and rail replacement, more popular.

Other new techniques have been developed to ease the maintenance burden. Heat-treated or premium alloy rails on sharp curves and steep grades, and in station areas, have been used to prolong rail life, reducing the frequency of rail work. Replacement of jointed rail with welded rail in subways has also reduced maintenance, extended rail life, and reduced noise and vibration.

Direct Fixation Track

The difficulty of maintaining tie and ballast track in the underground environment has caused engineers to search for underground track structures requiring less maintenance and rehabilitation. Direct fixation track has such qualities and in addition its use has reduced the total tunnel height needed; approximately 6 to 12 inches can be saved in a box section structure with direct fixation track, due to the elimination of ballast. In the case of circular tunnels, direct fixation track allows comparable reductions in the tunnel diameter.

The earliest and perhaps most extensively used direct fixation track structures consisted of timber ties embedded in concrete. Typically, in this application, short wooden ties are used under each rail, allowing an open drainage trough to run down the center of the track. The concrete, which secures the short stub ties, is a "second pour", that is it is poured in place separately from the structural invert of the tunnel. Conventional tie plates with cut spikes or

Early direct fixation track emplo wooden ties embedded in concrete.

screw spikes secure the rail to the st using timber, there is some freedon alinement, gage, and profile of However, there is a price to this fle stub ties can be spiked-killed long b wear out due to rot or splitting. B placement of embedded ties is a di some transit agencies no longer use construction.

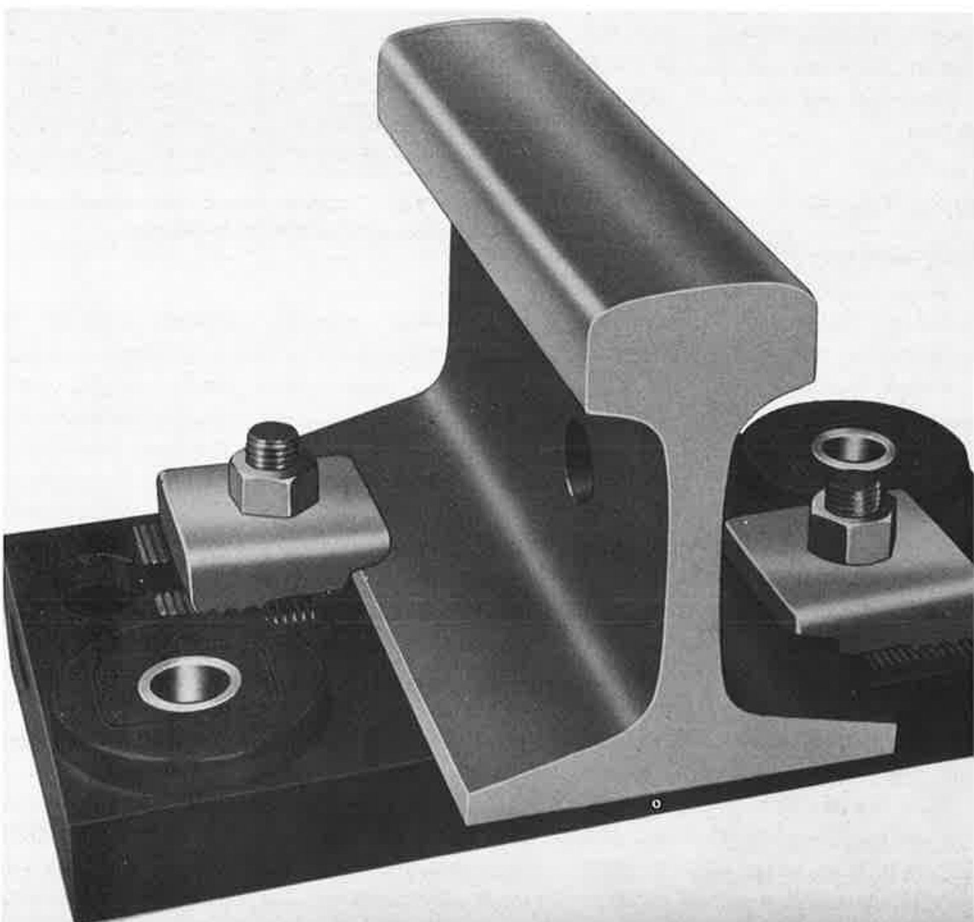
Another disadvantage of em track is its propensity to abet ground-b and vibration. While an embedded tir some resilience, it is considerably stiffe and ballast combination, or than a res fixation track fastener.

Virtually all new underground planned or in construction uses resi fixation fastening systems. The fasten must accommodate the primary load the vertical forces caused by the we moving train, the lateral forces from the rails as they contain the train on straight and curved track, the longitudinal forces applied by the train as it accelerates or brakes, and the thermal-induced forces (continuous welded rail). Another factor which must be accommodated is the uplift force on the fastening system. As the vehicle moves along the rail, the rail is depressed under a wheel but bends or bows in the opposite direction a short distance ahead of and behind the moving wheel. As it does this, the rail attempts to raise up and pull away from the fastener or track slab.

Tie and ballast track is a relatively elastic system. As the rail deflects downward or sideways under a passing load, the load is spread over a number of ties. It is
ing" system, adjusting to the slo
load due to shifts in alinement ca
or long term movement of the su
structure, and has the capacity to
later to correct for such accumulat
direct fixation systems are not as f
and ballast track. The advantage
the track is more likely to retai
alinement and sustain locked-in st
disadvantage is that failures, or i
the direct fixation system are diffic

The resilient elements of the
tem can help correct minor irreg
surface of the track slab. This resil
distribute the wheel load along th

Typical direct fixation fastener.



Lack of performance data has led t deficiencies and related performance as evidenced by this installation.

ing extreme stress concentrations in the slab or rail which could occur if the rail sat directly on the concrete. The extent to which vertical and lateral loads are distributed depends upon the elasticity of the fastening system. The softer the fastener, the further the load is spread. A relatively rigid fastener will not distribute the load well and will give rise to stress concentrations in the rail and slabs.

Vibration isolation is another major function of resilient track fastening systems. Fasteners should be very flexible in order to attenuate lower frequency vibrations which generate ground-borne vibration. However, if the fastening system is too flexible, the rail can lose its gage or even roll over on curves. Thus, fastening systems must be compromises; some of the vibration isolation capability must be sacrificed to achieve a stable track and, if more effective vibration isolation is required, other methods must be employed.

There is a wide variety of fastener systems and hardware now in revenue service. An even wider variety has been used in test installations. The theoretical load environment and the actual performance of these direct fixation systems have been researched in a number of UMTA studies. One such study, "Direct Fixation Fastening Systems" (12), reports on the deployment of, and experience with, direct fixation systems on American urban rail systems. In another study, test data on fasteners tested in use on the Washington Metro is being analyzed by the U.S. Department of Transportation, Transportation Systems Center.

Fastener Failures

Some transit agencies have had few problems, while others have h serious difficulties, with the mechanic mance of resilient track fasteners. sponsored studies have been mad detailed questionnaires and on-site visi sit system and railroad installations, fixation fasteners. UMTA has also s detailed investigations of fastener pro part of larger studies of track/vehicl tions. There is a need for further laboratory testing and analytical work such problems.

The most frequently reported type involves the anchor bolts which se fastener to the slab. Many of these failu from faulty installation. For example, g to secure the bolts or inserts must be mixed and used within a limited time in holes. If these procedures are not follo ficulties can be expected. Bolts loosen allowing fasteners to move laterally. one fastener can lead to failures of fasteners, particularly on curves wh lateral forces are present.

Fasteners with bolted clips holdi or the fastener in place, which rely o mating with a serrated (grooved) s lateral adjustment, may fail prematur wear or corrosion of the clips and/or s This can lead to gage-widening, exacer problem of rail replacement. This pro encouraged some transit agencies to with the requirement for lateral adjustment after installation.

Some transit agencies report that fasteners which are bolted to the rail require frequent inspection to insure that they are maintaining proper tension. This is also true for anchor bolts. Adjustable fasteners which rely on bolt tension and friction between the base plate and track slab to retain their alinement and gage are especially dependent on proper tension. However, inspection of some fastener types is particularly difficult because critical elements of the fastener system are hidden from view.

Certain double plate, bonded fasteners suffer mechanical failure, due to quality control problems during manufacture, or basic design deficiencies. Design deficiencies can arise from a lack of sound information on the actual conditions under which the fastener must operate. Vehicles with poorly designed primary suspension (the springing between the axle bearings and truck frames), or with cylindrical wheel treads, produce extremely high lateral track forces on curves. Installed on track with errors in track alinement, tight gage, or other track or vehicle abnormalities, the track fastener can be subjected to more severe loading than ever anticipated by its designers.

Investigation of the fastener load environment is currently being conducted by the Transportation Systems Center. Previous testing has resulted in the development of spring clips as rail fasteners, and the development of better insulating materials. Areas still to be explored include improvements in resilience in the lateral direction, more resilient accommodation of uplift forces, improved resistance to corrosion, and better methods for anchoring fasteners to the track slab. The capabilities of the various fastener systems to reduce ground-borne noise and vibration are being studied under an UMTA grant by the Chicago Urban Transit District.

Fixation Types

The direct fixation systems now in use or being installed are of three basic configurations: continuous supported rail, unbonded track fasteners, and bonded track faste
tion, there are two resiliently su
systems designed to provide greate
tenuation than conventional fasten
mounted ties and floating slab trac

Continuously Supported Ra

The continuously supported
perhaps the simplest direct fixatio
has proven to be one of the mor
system uses a continuous strip of
resilient elastomer pad, about 3/
thick and the width of the rail bas
rail. Cast metal shoulders are in
track slab, approximately 30 inc
sulators of reinforced plastic, co
and plastic, or elastomer are posit
shoulder, separating it from the ba
Spring clips which bear on the base
the insulator are inserted in the
continuously supported rail syster
the fastening system used with co
cept that the supporting pad is thic

The first application of this co
fixation track was in Great Britain,
used on test sections of at-grade
1968. Subsequently, its use has ex
grade, elevated, and underground
countries in both urban and interci
tions. In several situations, it has
replace tie and ballast track at the
tification of tunnels, when the tra
lowered to gain clearance for
catenary.

Because the width of the re
limited to the width of the rail bas
to be relatively stiff to keep the
moving excessively in the lateral
can be a problem on curves. Be
limitation, the ability of continuo
rail to attenuate groundborne nois
is not as good as that offered by n
track fastener systems.

Unbonded Track Fasteners

The New York fastener, an u
fastener system, uses an elastome

under the rail. The pad is supported and constrained laterally by a steel baseplate having a cross section shaped like a channel. The rail is held down by cover plates bearing on elastomer pads on top of the rail base. Each fastener uses four bolts anchored in the track slab to secure the rail and the fastener assembly to the slab. The New York fastener has no lateral adjustment after it is installed, though vertical adjustment is possible with shims.

The New York fastener, like continuously supported rail, has the pad directly under the rail, so that the pad has to be fairly stiff to maintain lateral stability of the rail. Because the bolts precompress the elsastomer pad, the amount the pad can deflect under load is reduced. Thus, the New York fastener is not as good at reducing vibration as more elaborate fasteners.

Another fastening system, the Toronto fastener, uses a modified tie plate directly under the rail and resting on an elastomer pad. The rail is secured to the plate by bolted spring clips, and the plate, in turn, is secured to the track slab by two bolts. The bolts are separated from the plate by insulating sleeves and washers to provide electrical isolation. These fasteners have given years of successful service in Toronto, Canada on conventional slab track and on floating slabs. Variants of the Toronto fastener are used to hold restraining rail and special trackwork. The fastener has no capability for lateral adjustment after it is installed, although vertical adjustment is possible with shims.

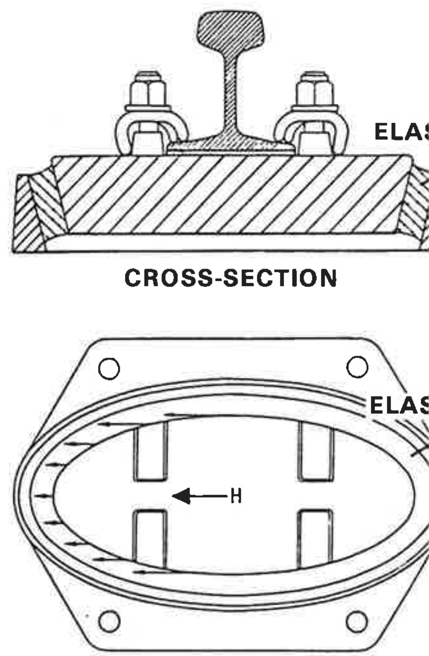
The resilient pad of the Toronto fastener is located under the plate, allowing the pad to be wider than those used directly under the rail. Because the load is spread out laterally, a softer pad can be used without sacrificing rail stability. The softer pad provides somewhat better performance in reducing vibration transmitted to the slab. There are limits however, and, in particularly sensitive areas, Toronto had to resort to more elaborate means of controlling groundborne noise and vibration.

The Toronto fastener is comprised of many parts and, like the New York fastener, it relies on bolts to hold it together and secure it to the track slab. Other transit systems are now developing variations of the Toronto fastener, usin of spring clips to clamp the rail to the pla second set of spring clips, resilient insul embedded shoulders (similar to those u continuously supported rail) to sec fastener to the track slab.

Bonded Fasteners

The simplest version of the bonded has a single base plate bonded to a res under the rail. The advantages claimed ed fasteners in general are that the elast perform quite efficiently, there are rela parts to handle on the job, and the fas be made corrosion resistant.

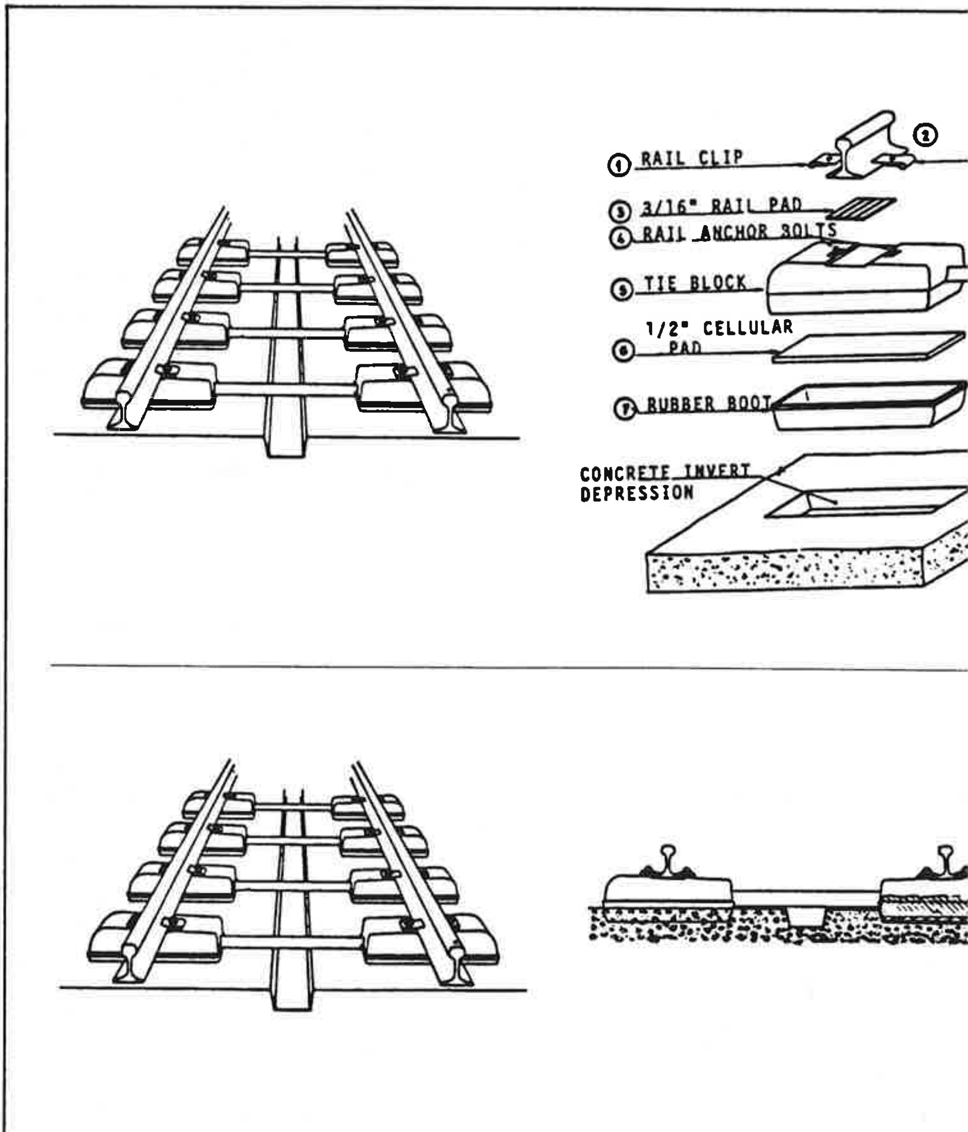
The single plate bonded faste Toronto fastener, and the continuou ported rail system have little or no res the lateral direction. Single plate fasteners use a custom-made plate, ra



The Cologne fastener was designed undesirable ground vibrations.

off-the-shelf plates as used in the Toronto fastener. Thus, the plate can be wide in the cross-track direction. The extra width, plus the characteristics of the bonded elastomer, permit use of a softer pad than found in the other fastener systems, resulting in improved vibration isolation.

The double plate bonded fastener, available from a number of manufacturers, uses two steel plates sandwiching an elastomer filling and is positioned between rail and slab. in concept to many vibration (shock mounts) used to support earlier versions of these sandv clamped the rail to the top plat clamp and bolt. Newer models us eliminating the problems of insta maintaining proper bolt tension. tie the bottom plate to the slab. the elastomer pad is not precomp



Resiliently-supported ties are an alternative to slab track for control of vibration.

the top plate can deflect under load, thus reducing vibration transmission to the track slab. Some lateral and longitudinal movement is possible, the elastomer pad working in shear. Such movement is limited by proper shaping of the base plate or by other mechanical means

The vibration isolation characteristics of this type of fastener are superior to those of other fastener types described earlier. However, like them, this type absorbs vertical forces in compression, which is a less efficient mechanism than shear for vibration damping.

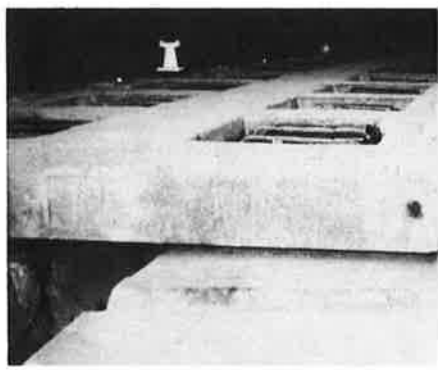
The Cologne Egg, so called because of its shape, is another fastener system, developed by the Cologne, Germany transit system. It was developed as a super-resilient fastener which would also eliminate the need for expensive floating slabs in new tunnel construction. The Cologne Egg uses an elastomer in shear to absorb vertical impacts. It allows vertical deflection under load and also provides cushioned lateral restraint to the rail because of its shape. It requires, however, more construction depth than other fasteners. Although relatively expensive, the Cologne Egg is reported to be a high performance and effective fastener. UMTA is sponsoring a test of the Cologne Egg fastener on Boston's transit system through a technology deployment grant program.

Resiliently Supported Tie

A special fastening system, which has been shown to be particularly effective in reducing ground-borne noise and vibration, is a resiliently supported tie developed in France. The rail is fastened to a duo-block concrete tie which is embedded in a second pour concrete slab. The lower portion of each concrete tie block is encapsulated by a closed-cell elastomer foam boot, which allows the tie to deflect under load, significantly reducing vibration transmitted to the track slab. The rails rest on thin elastomer pads, mainly for electrical insulation, and are secured by insulating clips, held in proper compression by bolts. The resiliently-supported tie requires a somewhat greater depth of construction than conventional track fasteners.

Floating Slab Track

Floating slab track is not a track system per se, but a special type of construction intended to provide a hig of isolation for ground-borne noise a tion. The entire track slab is supp relatively large, thick, and soft resilien that it "floats" free of the tunnel invert rails are attached to the track slab with tional resilient track fasteners or by tinuously supported rail system. The ra ing system provides electrical insula limited vibration isolation. In principle, tional energy is consumed by mo massive track slab around on its sof pads, leaving little to escape to th structure.



Typical section of floating sla construction.

There are two basic types of floa The first is the continuous floating slab tensively in the Washington Metro. pads, "glued" to the tunnel invert, su manent sheet metal forms. Reinforcin placed within the forms and the conc slab is poured and finished to accura The track fasteners and rails are then The gaps at the joints are filled with ela keep out dirt.

The second type of floating slab is ble tie", or discontinuous, floating slab in Toronto. The track slab is made concrete sections about 5 feet long, 10 and 1 foot thick. Each section, resting on resilient pads, is held away from the tunnel walls, and from other slab sections, by additional elastomer pads. Troughs are left in the top of the slabs to accept a second-pour slab, or grout pad, which supports the track fasteners and rails. This method of construction provides for final adjustment of the rail alinement, profile and superelevation.

Both systems have similar vibration isolation performances. Airborne noise within the tunnel is slightly less with the discontinuous slabs are that they are easier to install than continuous floating slabs and, in case something goes wrong, they can be removed or adjusted — an option not possible with the continuous floating slab. In fact, one transit system suffered the failure of the support pads at several locations along its continuous floating slab track, and is now faced with finding a solution to this problem.

Another transit property did not get the vibration isolation performance they needed from their discontinuous floating slabs in several sensitive locations. Lighter slabs than those recommended by the acoustic consultant had been installed, resulting in excessive vibration at or near the resonant frequency of the neighboring structures. Vehicles with hard primary suspensions compounded the problem since they generated vibration peaks in this same frequency range. The problem was partially corrected by adding more mass to the slabs to lower their natural resonance frequency.

Floating slabs, properly designed and installed, are effective but are also expensive to construct. The depth needed is only slightly less than that needed for tie and ballast track.

Although continuous floating slabs can be used to support special track work using direct fixation fasteners, Toronto and Boston have chosen to support trackwork, such as switches and turnouts, on wood ties and ballast carried by short sections of continuous floating slab. This "belt and suspenders" approach is expensive to build but it provides extra capability for vibration reduction, can be easily adjusted if necessary, and does not require special fasteners.

Special Consideratio
Curved Track

The interaction between vehi
the track on curves is especially t
urban rail systems because the
quite sharp, and inordinate wear
produced. Track maintenance di
pounded by space and time cons
urgent to understand and minim
fects of such interaction. Cons
Department of Transportation is
wide variety of programs concer
vehicle dynamics and noise abate

The basic problem is that a r
travel in a straight line. When it re
the car body, trucks, and whee
forced to change direction by the
rails on the wheel flanges. This e
wear of rail and wheels; increase
on the rail supporting structure
suspension; increased dissipation
energy; increased noise; and u
quality.

The interaction of wheel and
is extremely complex and not ful
Rail-car wheels are rigidly fixed t
must turn at the same speed. O
wheel on the outside rail must c
linear distance than the wheel on
Since they are constrained to rota
speed, this difference can only a
page of treads with respect to rails
therefore, as "slip".

Both axles of a truck are als
the suspension system to remai
parallel and centered within the t
that little or no steering of the ax
This mismatch between the direc
wheel is trying to roll, and the
forced to roll as it rounds the c
"crabbing". In addition, when th
makes contact with the rail it d
tread sideways across the rail. Thi
wheel with respect to the rail is
All of the slip and creep motion
tread and sliding of the flange res
tion, and noise.

On curves, centripetal force is required to keep the vehicle in the curved path. As in highway practice, rail curves are banked, the outer rail being laid higher than the inside one. This superelevation is designed to provide the centripetal force and in so doing the related lateral wheel and rail forces are reduced, becoming zero at the curve's design speed. Traditionally, it has been believed that wheel and rail wear on curves is primarily a function of improper speeds or improper superelevations. This is being challenged by recent studies. It appears that slip and creep forces and the relative smoothness of the curve may have an even more important effect on vehicle and track interaction and thus on wheel and rail wear.

The shape of the wheel tread also has an effect on curving performance. Most railroad and transit vehicle wheels have a tapered or conical tread. As the wheel moves toward the outside of the curve the large diameter portion of the tread of the outer wheel is in contact with the outer rails, and the smaller diameter portion of the inside wheel is in contact with the inner rail. This effectively increases superelevation and reduces the mismatch in distance travelled by inner and outer wheels. Tests in Washington indicated that tapered wheels produced significantly less lateral load on the outer rail than cylindrical wheels. Cylindrical wheels had been chosen originally because it was believed that tapered wheels can

Restraining rail used to control wear and provide protection against derailment on a sharp curve.

Guard rail used on elevated structu special track work to protect derailment.

exhibit a tendency to "hunt" back and one side of the track to the other. Ind experience indicates that some of the tempts to cure hunting through des wheel tread, suspension system, and interface, can lead to serious proble cessive wear and even derailme underscores the need for further analysis of track/vehicle interactions.

UMTA/TSC experiments with A Washington vehicles have indicated t ing longitudinal springing stiffness (by the elastomer axle box mountings) limited degree of axle self-steering wh in improved performance in curves. In ta car, the reduced longitudinal sti helped keep the wheelsets of the truck each other on straight track, compe inaccuracies in truck assembly. S curacies previously had resulted in preferred left-hand or right-hand c pending upon the amount that axles v parallel. The UMTA/TSC investiga showed that reduction in vertical sti vehicle's primary suspension resulted impact on the track and less ground-b and vibration.

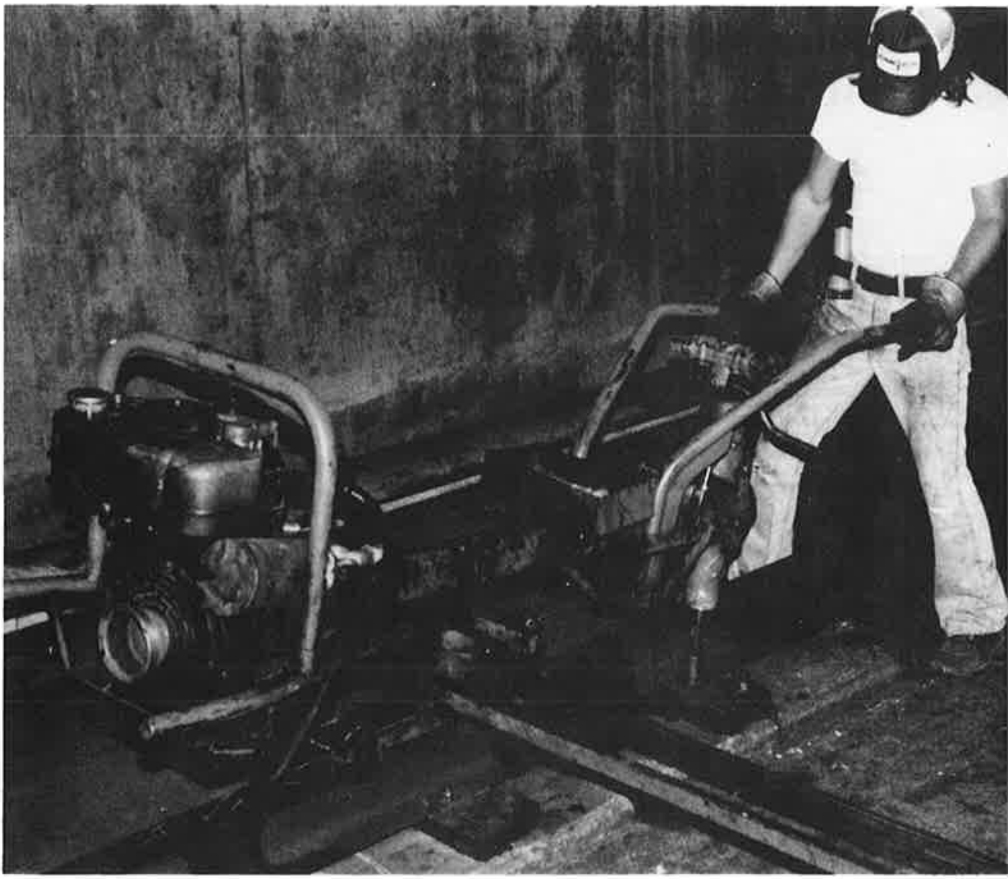
With or without vehicle improve track engineer still has to cope with ra curves. An UMTA study on restrainin and (11), examined various means of rail life on curves. A restraining rail is a rail placed close to the inside face of the inner rail on a curve, to provide a guiding surface for the back or inside surface of the wheel flange. On curves, to reduce wear, the width of the flangeway gap, and the gage of the track are set to hold the flange of the outer wheel just clear of the outside rail.

While it is possible to lubricate wheel flanges and the guiding face of the outside rail on curves, many transit systems are reluctant to do so as the lubricant can creep onto the wheel tread and running surface of the rail. With frequent station stops and close headways between trains, urban rail systems need dependable braking, and cannot tolerate degraded braking due to slippery rails. In-track lubricators, which apply lubricant to the back of the wheel flange and thence to the restraining rail, do not get lubricant on the tread and running rail and consequently do not degrade braking performance. For this reason, many systems use restraining rail on curves because it is the only way by which they can safely apply lubricant. The lubricant reduces friction and propulsion energy requirements, and greatly extends the life of the restraining rail. It can also reduce noise. Because the restraining rail keeps the flange of the opposite wheel away from the outer rail, that flange's life expectancy is enhanced as well, even though both inner and outer rails and the wheel treads are still subject to wear from slip and creep forces.

Restraining rail is also used to prevent derailments on sharp curves (generally less than 500 to 700-foot radius), on elevated structures, and through crossings and switc regions, there is no need for flange the restraining rail serves merel (hence the name guard or check derailment.

Girder or grooved rail is an restraining rail used exclusively on set in pavement. Plain girder rail radius curves and also on tangen shallow lip, intended to keep pavin of the flangeway. On sharper guard-rail is used which has a thic than the running surface of the r flangeway opening about 1 3/4 in acts as a restraining rail. Track ga by about 1/2 inch to keep the fla posite wheel clear of the outer rai

In addition to restraining rail, t means of extending rail life on treated, head hardened, or premi are being used by urban rail system pose. These rails are harder and le to abrasion than the normal contro Some transit agencies specify pre both running rails and the restra sharper curves. Premium rails are and special precautions are welding. On unrestrained curves, agencies use premium rail for bo perhaps, a radius of 1400 feet. F up to 2800 feet, premium rail w but only on the outer rail. It woul carry out more extensive studies, tests, of transit experience with and develop criteria for its use.



Use of large specialized maintenance equipment is constrained by space in th environment.

5. Maintenance and Rehabilitation

Track maintenance covers inspection, routine repair, and preventive maintenance including spot replacement of defective components, and emergency repairs. Track rehabilitation work includes major replacement and upgrading of the track structure. Maintenance work is usually performed during normal service hours or during short periods of time when track is out of service, especially in the case of systems which shut down for four to five hours at night. Track rehabilitation is done by closing down one track or an entire line as required.

When tracks are closed, serv
red to other tracks or even mode
easily carried out during exten
working periods when late and e
be replaced, or during weekends
light and more easily diverted to
rehabilitation project may requir
down of a line for a period of se
months. While total shut-down gi
ty the most work for each dollar sp
track work, the costs of alternati
short and long term loss of riders h
sidered as well.

It is obvious from the meag
given in Table 3 that data on th
track components is not very c
situation may be changed by c
sponsored research to develop
maintenance management inforn
and a data base of compon
performance.

TABLE 3
USEFUL LIFE OF TRACK COMPONENTS

		Useful Life (Years)		
	NYCTA	MBTA	CTA	R
Running Rail				
Tangent Track	20	10-25	40	1
Curves	5-6	1-12	10-20	1
Contact Rail	65	*	*	t
Switches	*	7-10	10	7
Frogs	12-15	20	*	1
Turnouts	5	*	*	5
Lubricators	*	40	40	t
Insulated Joints	*	2-10	*	2
Switch Points	5	1-4	*	.
Ties				
Protected	40-50	35-40	40	3
Exposed	20	10-25	10-30	1
Ballast	40	10-30	2-20	2
Chair				
Wood	*	*	40	t
Ceramic	*	*	8-40	8
Fiberglass/Plastic	*	10	*	t
Bolted Joint	20	*	*	t

*Not reported.

Source: Information from UTD Corporation.

Previous chapters have dealt with many of the details of track design and construction as they relate to reducing the need for future maintenance work. Use of continuous welded rail, premium rail, and/or restraining rail on curves, are typical approaches for extending the service life of the track structure. However, even the best components in an ideal environment, carrying well-designed vehicles, are subject to wear and must be inspected, maintained and eventually replaced. In this chapter some of the maintenance problems, techniques, and future needs as seen by the operators of the urban rail systems are discussed.

New systems are not immune from the need for track maintenance. Embankments will settle during the early years of operation. Poorly designed or installed track fasteners will fail. Track, like any other system, will have "bugs" which must be worked out. Maintenance forces also have to go through a learning period. Rehabilitated lines may need special care during the first six to twelve months of revenue service.

A major rehabilitation project, as far as the track structure goes, is similar in complexity to building a new line. However, because rehabilitation usually occurs under a serious time constraint, some things cannot be done as well as in new construction. The joining and anchoring of continuous welded rail may have to be done during non-optimum temperatures, leading to later difficulties such as pull-aparts in winter, or buckles (sun kinks) in the summer. Track lining and surfacing may have to be done in very hot weather, as a summer shutdown may be the only opportune time to do the work, resulting in track buckling while work is in progress.

The UMTA study, *U.S. Transit Track Assessment and Research* (9), discusses maintenance issues and reports the proceedings of a track maintenance workshop where representatives of transit agencies made their needs known. Subsequently, some of these maintenance problems have been included in other studies of track components. Solutions developed in these studies will be examined and applied in the field, with the help o[f] transit agencies.

Inspection and Management Informati[on]

To make the best use of track m[aintenance] and rehabilitation dollars, it is necessa[ry to know] where, when, and how much work [should be] done. The traditional approach to as[sessing the] need for work consists of trackwa[lkers who] visually inspect track at specified [intervals,] perhaps once or twice a week for rev[enue track,] and make minor repairs, such as tight[ening] bolts, as they go. Unfortunately, in [modern] construction, a man with a track wre[nch cannot] repair much of anything, and cannot [detect] defects in rails or fastening systems.

Trackwalkers look for track defe[cts such as] broken rails; badly worn switch poin[ts;] or severely battered switch frogs; loo[se] or missing bolts at rail joints, track[,] restraining rail assemblies, or within s[pecial] work areas; damaged third rail [...] broken or missing rail bonds and oth[er] connections to the rail; signs of exce[ssive move]ment of rail and/or tie plates; and for[eign objects] on the track.

An experienced track maintena[nce super]visor or manager should be able to [spot] these defects and should be able [to make a] general evaluation of the track by ri[ding] on revenue trains and walking it for [in]spection. A poor ride, and track with [...] horizontal and vertical alinement th[at is ob]vious to the eye, are good indicatio[ns that cor]rective action is required. The walkin[g] should also give a reasonable idea of [...] of badly worn rail and special trackw[ork,] problems of fouled ballast, draina[ge] condition. More accurate measure[ments are] usually needed to determine whe[n and how] much should be done. For exampl[e, measure]ments of the rail head profile are [...] determine when wear is sufficient to [...] replacement.

Hand-measurement of track geometry parameters is still widely employed.

In the decade prior to World War II, a private company operated a fleet of rail detection cars over the intercity rail network. After the war, New York City Transit Authority had the same company develop a special car suitable for its use. More recently, small vehicles on road/rail automotive chassis have been developed and can be used on most of the urban rail lines in the U.S. Advances in electronics have brought about the deployment of portable hand-held measurement units, suitable for detecting defects at joints and in special trackwork.

The automatic measurement of track geometry can also provide useful information for

determining faults in track stru
dicating areas that need attentior
intercity railroads and track main
ment suppliers have developed
variety of track geometry measu
and vehicles. The most rudiment
manually operated, usually meas
parameter such as gage, or cros
elevation of the two rails). Mea
then manually recorded in a fi
most sophisticated device is a f
with electronic and mechani
devices which can simultane
horizontal alinement and vertical

BART's track geometry car is a step towards prioritizing track maintenance automation.

rail, cross level, gage, and other parameters and record them in analogue or digital form. Some of these rail cars operate at fairly high speeds covering hundreds of miles in a day.

Elaborate measurement systems can produce great volumes of data. However, if the data is difficult to interpret, it is of little value. The Washington Metro has begun the development of a "Track Maintenance Management Information System" (TMMIS) as part of a larger program for improving transit track maintenance procedures funded by UMTA. The project will review existing practices at WMATA and selected other systems, and then develop and implement an appropriate management information system. The maintenance-of-way scheduling algorithm will accept output from a track geometry measurement system and compare it with desired levels of track quality to assist in cost effective scheduling of maintenance work.

Training Methods

The development of human resources is a vital part of an effective maintenance and rehabilitation program. Lack of investment in U.S. urban rail systems during the years just before and after World War II, and material and labor shortages during the war, led to both deferred maintenance and loss of skilled maintenance personnel in the transit industry. In recent years, inflation has restricted maintenance

budgets, leading to reluctance to spe
on training new staff, while more libe
plans have brought about a serious
perienced personnel. At the same ti
rehabilitation programs at Amtrak, C
the private railroads, in conjunction v
itiation of new urban rail systems, hav
the demand for trained maintenanc
and supervisors.

The Washington Metro TMMIS
engineering support project will inclu
effort in track maintenance training,
classroom and in the field, for wo
supervisors at various levels. Sta
maintenance tasks will be establi
methods of evaluating the performan
tasks will be developed. Intercity railro
the same problems as the transit ind
successfully implemented such tra
grams and it may be possible to ada
transit industry use.

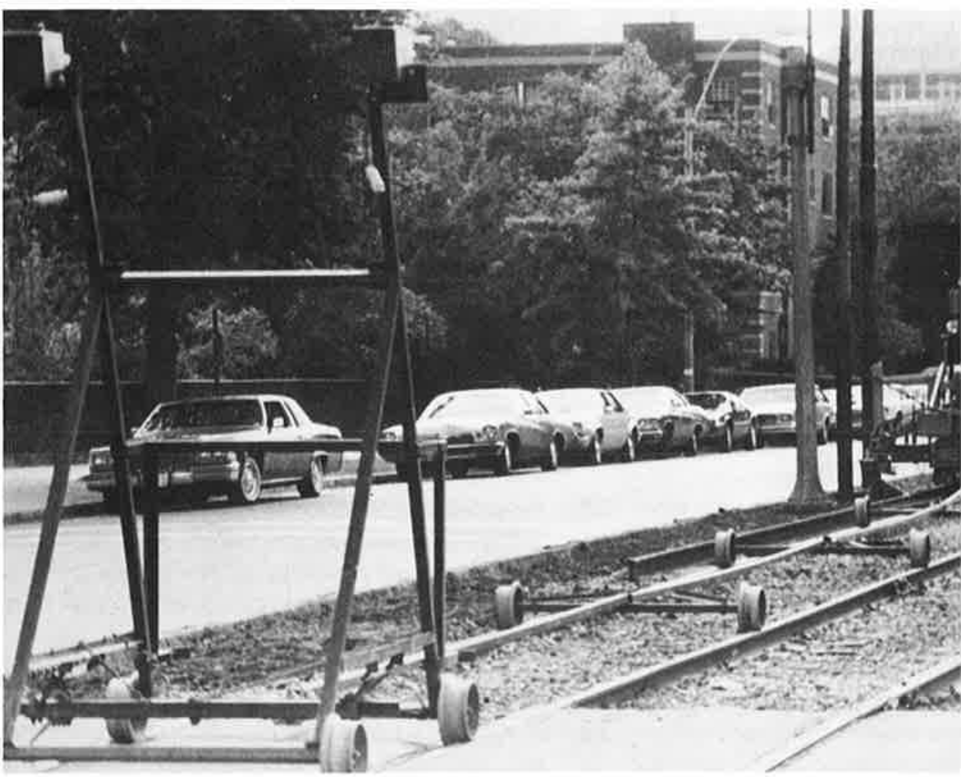
Once the Washington program
tested, it will be evaluated and a
package of industrial engineering s
cluding TMMIS, will be available for
entire transit industry. It is expected t
also lead to improved techniques for
life cycle costs of track structure,
account both initial and maintenance

Maintenance Equipmen

In the past three decades,
advances have been made in the me
of intercity railroad track maintenance
work can be done faster and better
new machines than by the old manua
with significantly less manpower. Pro
different machines, each performing
function, or several related functions,
the railroad track and, in a single pass
entire track structure in assembly li
Miles of track can be completely rep
the ground up, in a single workday.

Unfortunately, not all of these
and methods can be applied to
systems. The presence of a third rail,
rail, and other track appurtenances

Tamping and lining track in the urban transit environment.



off-the-shelf railroad machines unusable, or require significant and costly alterations to the machines' designs.

Tight clearances in tunnels and at high-platform rapid transit stations place severe restrictions on the use of some kinds of machines. Close track spacing, as found on older rapid rail and light rail lines, is also a problem. For example, a tamper/liner employing jacks which rest on the ballast shoulder, can raise and level track, but not aline it without disturbing the alinement of adjacent track.

Ballasted track on tunnel inverts or on elevated structures cannot be plowed out for replacement or cleaning by railroad-type, undertrack sleds or ballast cleaning machines, because of the third rail and the tight clearance between tie ends and adjacent concrete-encased ducts and safety walks. Thus, transit line ballast either must be dug out by hand—a slow costly process—or the track must be lifted and replaced enabling ballast removal by bulldozer and front-end loader.

Diesel engines, used to power most track machines, must, for use in transit subways, be equipped with exhaust scrubbers. In some cases, supplemental exhaust fans may be needed to maintain reasonable air quality for workers. Diesel engines, used for maintenance on surface lines in densely populated areas, may be restricted at night by local noise abatement requirements.

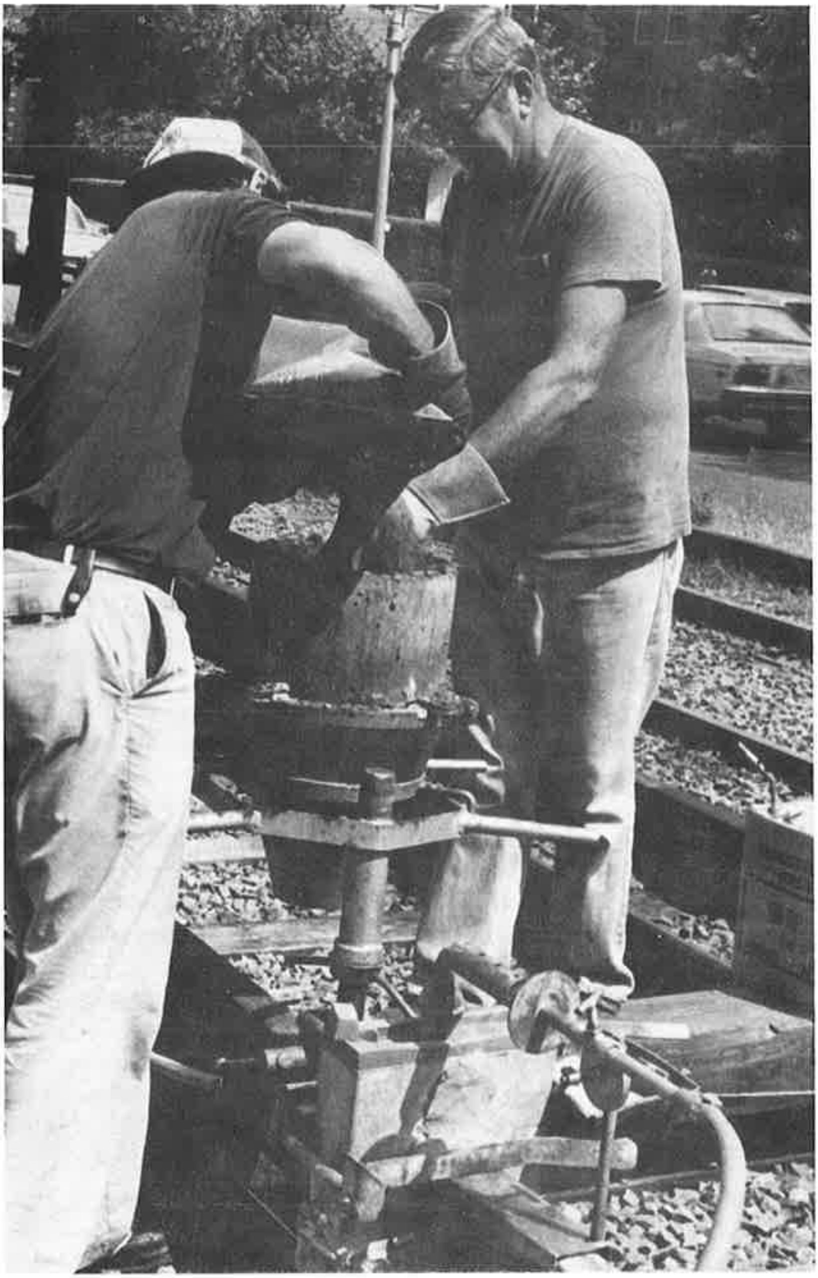
Mechanized intercity railroad maintenance machinery can be left near the job on sidings or be set alongside the track, using built-in equipment. In urban transit applications, convenient, over-night or temporary storage for equipment is not easily available on a restricted surface right-of-way, such as an open cut with side walls, or in a subway. Frequent obstructions, such as grade crossings on light rail lines also reduce productivity of large maintenance machines.

The handling of continuous welded rail is more difficult in subways or elevated structures than on main line railroads in open country. The sharper curves of urban rail also create problems. In general, specialized rail handling machinery is needed for urban rail projects, and often rail strings must be shorter, s
compared with 1,200 feet or more
This requires more, costly field wel
systems.

Urban rail systems vary conside
clearance envelope available for
ment. There can be significant variat
single transit system, as is the case in
Philadelphia. In addition to standard
Philadelphia, Pittsburgh, Toronto
BARTD system in San Francisco
wide gage track configurations. A
effort would be to assemble a
clearance envelopes from all syster
solidate them into a "family" c
outlines. These could prove mo
machine suppliers and track contrac
probable that one clearance envelo
developed for nationwide use, but a
of different outlines would be more
today's wide variety in showing wl
standard machinery is applicabl
indicating standardization possibilitie
ing the development of new
machines having widespread applic

The small total demand for
trains, the variety of clearance env
the specialized nature of the equip
urban transit maintenance equipme
both old and new urban rail systems
retired passenger cars were often re
as work trains. However, the m
weight cars do not lend themselv
alterations so that many transit age
using equipment built perhaps sever
ago.

The older transit systems are
the need to renew their subway trac
They need help to plan this work so
done in the most cost-effective m
also need help to determine which
improvements should be used to p
systems which will require less ma
the future. For these reasons the
Transportation Administration
maintenance and rehabilitation at
list of priorities for assistance to trar



Thermite welding of transit track is becoming widely accepted. Various steps in the process are shown here.

Bibliography

Reports on UMTA research and development described in this volume are available to the public through the National Technical Information Service (NTIS). NTIS is the principal repository and disseminating agency for all reports issued in conjunction with federal research and development activities. To order reports from NTIS use the order numbers (PB numbers) listed after each report citation in the bibliography. The lack of an order number following the citation means that the report had not yet been entered into the NTIS system when this publication went to press.

Inquiries about the availability or price of reports should be addressed to:

National Technical Information Service
Springfield, Virginia 22161
The NTIS Order Desk telephone number is
(703) 557-4650.

1. **A Bibliography on the Design and Performance of Rail Track Structures,** R.H. Prause, et al., Battelle-Columbus Laboratories, September 1974, UMTA-MA-06-0025-74-7, PB 238-129

This bibliography includes technical reference material concerning the design and performance of at-grade track structures for urban rail systems. While most of the material is directly related to track, there are some references on related topics such as rail vehicle dynamics, soil mechanics, stress analysis, etc.

This survey covers much of the published literature on track design, track loading, ballast, wood and concrete cross ties, rail and rail fasteners. It also covers rail wear and corrugation, rail defects, rail joints and track degradation.

2. **Assessment of Design Tools and Criteria for Urban Rail Track Structures,** Volume I, At-Grade Tie-Ballast Track, H.E. Meacham, et al., Battelle-Columbus Laboratories, April 1974, UMTA-MA-06-0025-74-3, PB 233-016.

This report is a critical review of technical factors concerning the design and performance of at-grade, tie-ballast track for urban rail systems. The assessment is based o[n] the literature and discussions with track design personnel. The evalu[ation] design loads and the criteria for sele[ction] tie size and spacing, ballast depth, parameters. Major track problems with rail joints, noise and rail wear fasteners, and rail corrugation. track design procedures are c[onsidered] adequate are identified. The re[port] detailed information for the engin[eering] of track, and recommendations f[or] and long-range research leading track performance.

3. **Assessment of Design Tool[s] for Urban Rail Track Struct[ures]** II, At-Grade Slab Track, H. et al., Battelle-Columbus April 1974, UMTA-MA-06-0 233-017.

This report is a critical r[eview of] technical factors which govern th[e] performance of at-grade slab track systems. It is based on a review o[f] and discussions with experienced personnel. The evaluation include[s] of slab structures now in use in f[...] followed by review of design and [pro]cedures used to characterize the su[...] support characteristics, the reinfo[rced] slab itself, and the subgrade suppo[rt]. document is especially useful [...] similar work reported in the literatu[re] highway or runway application[s] mechanism of load transfer into th[e] pletely different than in a rail sup[...]

4. **Laboratory Evaluation of [...] and Fastenings for Trans[...]** Hanna, Construction Laboratory, A Division Cement Association, March MA-06-0100-79-8, PB 297[...]

This report describes laborato[ry] concrete tie evaluation and pres[...] tests on ties and fastenings.

5. **Measurement Program for Concrete Ties and Fasteni[ngs]**

Track, A.N. Hanna, Construction Technology Laboratories, A Division of Portland Cement Association, March 1979, UMTA-MA-06-0100-79-2, PB 297-570.

This report outlines a measurement program to obtain data on the performance of standard concrete tie designs and associated fastening systems under field service conditions.

6. **Pilot Study for Definition of Track Component Load Environments,** T.R. Stagiliano, et al., Kaman Avidyne, Burlington, MA, February 1981, UMTA-MA-06-0100-81-1, PB 81-203-531.

This report describes the results of an experimental and analytical program to define vehicle-induced loading on an at-grade, concrete tie/ballast transit track structure. The experimental work was performed at the former DOT/UMTA test transit track, a well constructed and maintained track structure, in Pueblo, Colorado. A primary intent was to establish an initial data base which could be extended to include data from tests conducted on various transit track structural systems.

Track design methods and analytical computer techniques for predicting the load environment of the various track components were evaluated by comparison with experimental data.

7. **Preliminary Specifications for Standard Concrete Ties and Fastenings for Transit Track,** A.N. Hanna, Construction Technology Laboratories, A Division of Portland Cement Association, March 1979, UMTA-MA-06-0100-79-3, PB 297-850.

This report presents specifications for the materials, manufacture, and handling of prestressed concrete cross ties. It also includes requirements for rail fastenings for securing the running rails, and the inserts for anchoring both the rail fastenings and the traction power contact rail support bracket.

8. **Technical and Economic Feasibility Study of At-Grade Concrete Slab Track for Urban Rail Transit Systems,** A.N. Hanna, Construction Te Laboratories, A Division of Po ment Association, August 198 MA-06-0100-81-4, PB 82-113

This report presents a review of performance of world-wide slab track compares features of slab track sy those of conventional ballasted discusses methods of constructing systems. In addition, a cost comparis slab and ballasted track systems is Recommendations are made for futu efforts related to the development concrete slab track systems.

9. **U.S. Transit Track Assess Research Needs,** E.G. Cunn ENSCO, Inc., December 197 MA-06-0100-79-16, PC 80-19

This report describes track con current practices in track design, co maintenance and inspection; poter tunities for improvements; favorable that is available but not commonly us track systems; and needed research a tasks to meet identified needs. The evaluates research and support tasks importance, analyzes their costs ar and recommends a plan for a track re gram.

10. **U.S. Transit Restraining Rail Study of Requirements and** E.G. Cunney, et al., ENS December 1981, UMTA-MA-0 PB 82-176652.

This report describes current p the design, installation and main restraining rails; rail and flange lubri tices; and tests of the effects of lubrica vides information on the simplified costs and benefits of restraining rail and alternatives, deterioration of res components, benefits of lubrication cepts for improved lubrication syste and recommendations for programs ways to reduce rail wear.

11. **U.S. Transit Track Restra Volume II, Guidelines,** E.G.

al., ENSCO, Inc. December 1981, UMTA-MA-06-0100-81-7, PB 82-176660.

This report contains guidelines derived from the study of transit restraining rail requirements and practices. It also considers associated practices in the railroad and other industries. It includes recommended standards and practices for design, installation, maintenance and inspection; and suggestions for the evaluation of requirements for restraining rail installations. It includes descriptions and limits for measurable factors, such as gage and flangeway width, and descriptions of factors that normally are not measurable.

12. **Direct Fixation Fastening Systems — Deployment and Experience on American Transit Systen** den, Jr., et al., Wyle Lab orado Springs, CO, July 19 WR81-41.

This report contains detailed periences of U.S. and Canadian ties with direct fixation fasteni presents a compendium of the st direct fixation fastener technolo and maintenance on North A systems.

This report includes a summ tion from the transit systems sur mendations are given for future direct fixation fastener system pr

Glossary

Alinement:

The spatial relationships (designed or measured) between the various components of a track structure — especially the rails — or with reference to the overall straightness or curvature of the composite structure. The vertical alinement of a rail is also termed its profile. The difference between designed and measured alinement is termed its exception.

Continuous Welded Rail (CWR):

Rails joined together by various welding processes which may be done on the site of installation or at a remote location. Unlike jointed (or bolted) rail, expansion and contraction is not allowed — the rail is anchored to the ties to prevent movement.

CTA:

Chicago Transit Authority

Direct Fixation Fastener (DF Fastener):

A device used to attach the rails to a concrete slab which may be a tunnel floor, bridge deck, or a slab on an embankment. The fasteners usually include resilient elements to provide electrical and vibration isolation between rail and slab.

Flange:

The portion of the wheel extending radially beyond the wheel tread, which keeps the wheel on the rail and guides it along the track.

Gage:

The lateral distance between the rails, usually measured at a point 5/8 of an inch below the top of the rail. Standard gage is 4 feet - 8 1/2 inches (1435 mm).

Gage Widening:

Increase in distance between rails. The track gage may be intentionally increased on curves to reduce wear. Gage widening may occur with time as a degradation process.

Girder Rail:

A rail with a groove in the top modate wheel flanges and to paving material away from th case of girder guard rail, the lip towards the center of the track wheels around a curve.

Grout Pad:

A thin layer of concrete u port a direct fixation fastener or slab. Grout pads allow the trac install the track slab at its ap vertical location; the grout pad up the difference between the " and the precise level needed f

Guard Rail:

a) A rail located inside the run bridges or elevated structures wheels on the structure in case

b) Short rail section located running rail (providing a flange about 1 1/2 inches to 2 inch switches opposite the point wh cross, to prevent the wheel flan ing in the wrong direction.

Invert:

The poured concrete floor o tunnel. It may support tie and b or direct fixation track res separately-poured track slab.

MARTA:

Metropolitan Atlanta Rap Authority

MBTA:

Massachusetts Bay Transit Aut

NYCTA:

New York City Transit Authori

Restraining Rail:

An extra rail on curved track, u ly to reduce wear, but also derailments on sharp curves. It the track-center side of the inside running rail, closer than a guard rail, and bears against the back of the flanges of the inside wheels, keeping the outside wheel flanges clear of the outside rail of the curve.

Runoff:

The distance needed to make a change in the profile of one or both rails (See Superelevation.)

Slab Track:

Rails directly supported by a concrete slab placed on the ground, a bridge or the floor of a tunnel structure, without the use of conventional ties and ballast.

Special Trackwork (Specialwork):

Includes track switches, also called "turnouts", and crossings. Special trackwork may be composed of standard off-the-shelf components, or custom made units designed to fit a particular situation.

Spiral:

A transition curve between tangent and circular curve track.

Substructure:

At-grade track — the substr
passes all supporting materi
under the tie.

Superelevation:

The height by which the c
curve is above the inner r
banking. It reduces the lat
wear on the outer rail and p
comfortable ride.

Superstructure:

Track — The superstructure
the ties, fasteners, and rail
fastener, and rail).

Bridge — The superstructure
the bridge girders, or truss
which rest on the piers and

WMATA:

Washington Metropolitan
Authority.