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Subways

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Subways

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Subway's

BY
GROFF
CONKLIN

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THANKS are most especially due the members of the staff of the Board of Transportation of the City of New York for assistance in the preparation of this book, for many invaluable suggestions made to the author, and for permission to use official photographs.

And to the staff of the contracting firm of Spencer, White, and Prentis, thanks are hereby tendered for their co-operation in my study of the subway construction which they were undertaking.

GROFF CONKLIN

A NOTE ON THE PHOTOGRAPHS

ALL of the photographs in this book, with the exception of a half dozen or so throughout the text which are marked whenever they appear, were taken by the photographers of the Board of Transportation, over a period of many years. They are called *progress photos*, because they are taken in order to show how far work has progressed on a certain day of a certain month. The writing in white ink on most of them includes the actual number of the picture; the number of the route, or particular subway line which is being built (such as "R. 101") and the section of that route on which the actual picture was taken ("S. 9"); in some cases an accurate description of the subject and the street location of the picture—though many shots do not have this information on them; and lastly, the date.

Below is a picture of the room where all the photographs from the Board of Transportation were made for this book. The section of the room shown is the place where the photos are printed from the negatives.

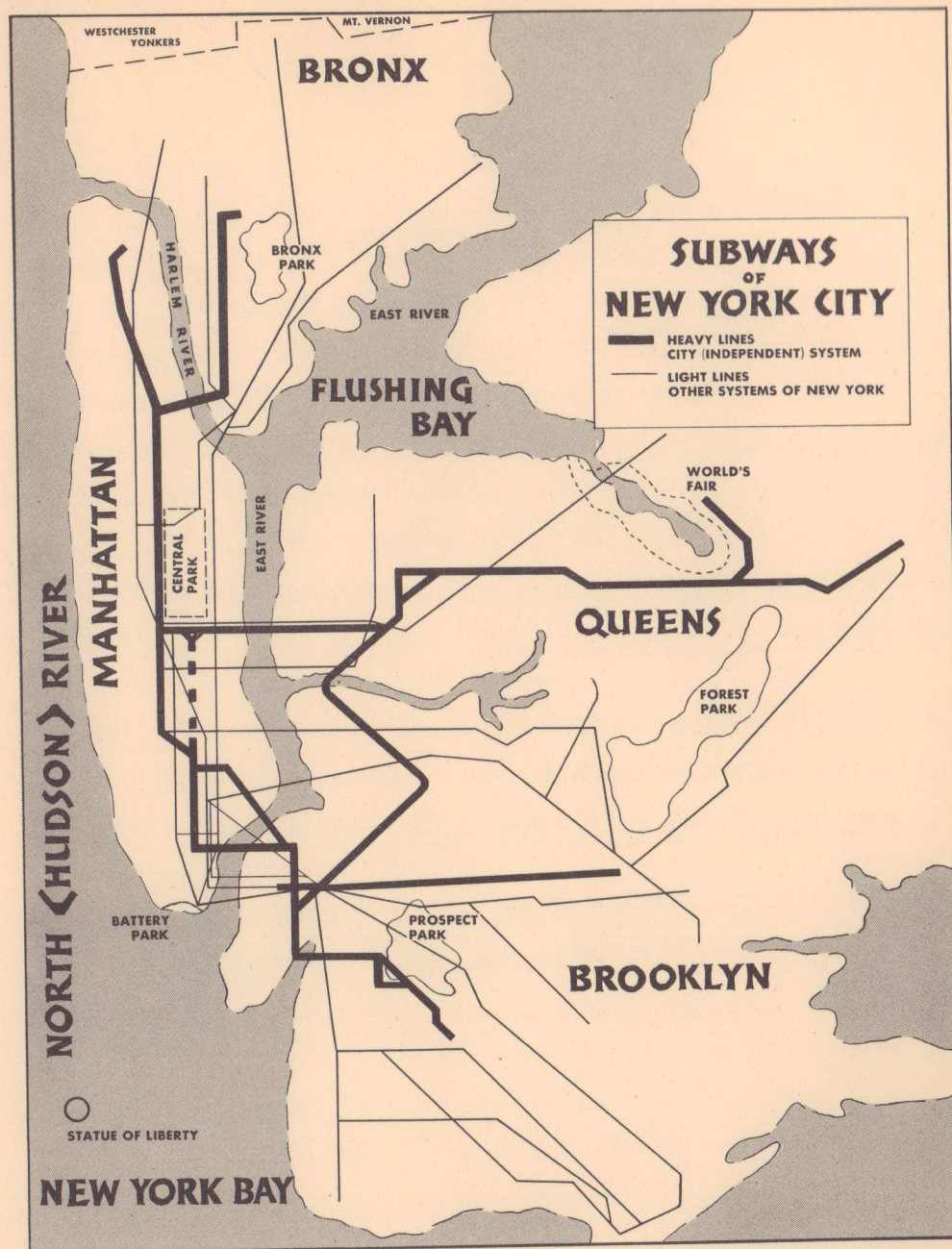


TABLE OF CONTENTS

1. BEFORE THE BLUEPRINTS	11
2. THE BLUEPRINTS	21
3. BEFORE EXCAVATION	35
4. THE EXCAVATION—CUT-AND-COVER	51
5. MORE ON EXCAVATION	75
6. TUNNELING	103
7. CONSTRUCTION	129
8. INSTALLATION OF TRACK	151
9. INSTALLATION OF SIGNAL EQUIPMENT, ETC.	165
10. SUBWAYS AROUND THE WORLD	183

ERRATA

Page 91—The pictures on this page should be reversed.
Page 197, Line 12—"Page 210" should read "page 212".



This gives an idea of the complex network of subway lines which exist in New York City. The same situation would be found in Paris and London, which have just as complicated systems. None of the elevated lines are included in this map, although elevated extensions of subway routes out in Brooklyn and up in Bronx are included. None of the Independent System (heavy black line) is elevated.

CHAPTER ONE

BEFORE THE BLUEPRINTS

ON A sunny morning early in April, 1938, a much-used one-ton truck drew up to the curb at Pitkin Avenue, far out in the borough of Brooklyn, New York City. So quiet is this neighborhood, with its rows of houses and small-town stores, that one would think it a hundred miles away from the skyscrapers of Manhattan. But actually it is only five miles distant.

The truck was laden with a miscellaneous collection of lengths of pipe, heavy inch-and-a-half rope, various tools, and a donkey engine. It might have been a plumber's truck, coming to fix someone's bathroom.

Three men in overalls climbed out of the cab of the truck and began unloading. They slid the donkey engine down wooden skids to the street, and laid out the pieces of pipe in the gutter—except for three heavy 20-foot sections, fastened together at one end, which they set up, with much straining and pulling, in the form of a tripod right in the middle of the sidewalk. Then they adjusted the engine, passed a rope through a wheel fastened at the upper point of the tripod, and started to break the sidewalk preparatory to digging.

By this time a crowd of curious folks from the neighborhood gathered about them, wondering what was going on.

"What are you fellows doing?" one of them asked.

"We're making borings," a workman told him.

"What for?"

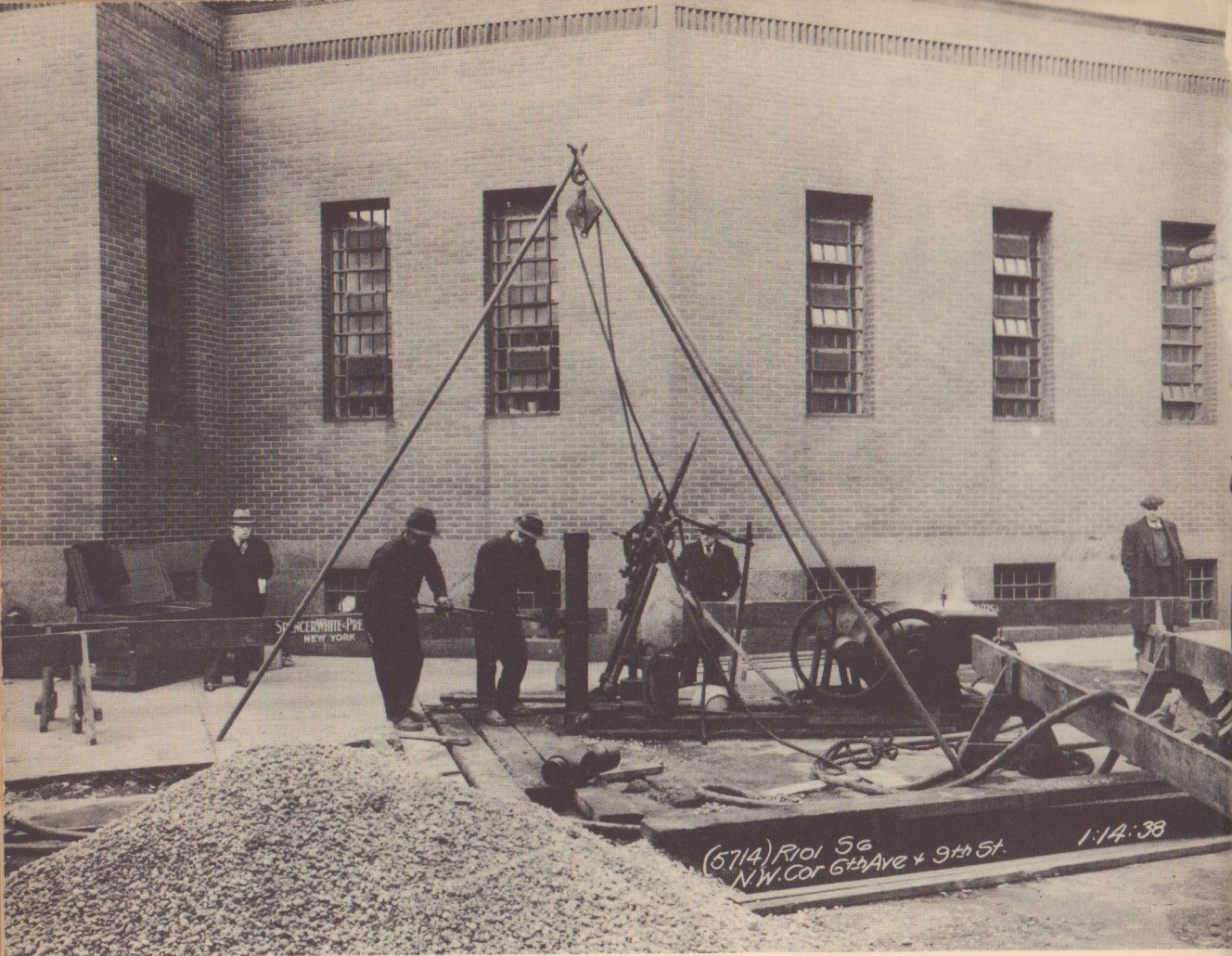
"Subways!" answered the workman.

Quickly the news spread. Pretty soon at least fifty people had gathered around to watch. Children, on the way to lunch from school, stopped to find out what the excitement was about.

What they were witnessing was the first simple step in the building of one of the greatest engineering feats man has ever accomplished—a subway! A railroad underground, free from all traffic dangers, where trains can travel from thirty to fifty miles an hour, carrying the inhabitants of an immense and congested city to and fro about their business.

The workmen finished digging the small hole in the sidewalk and placed upright in the hole a ten-foot length of four-inch pipe (its real name is "casing"). They tied a 350-pound pile driver to one end of the rope through the wheel at the top of the tripod. The other end of the rope they wound around the winch of the engine and started the engine going, pounding the casing straight down into the earth. Another length of the casing was then fastened to the top of the buried piece and pounded down, and still another, until more than thirty feet of pipe were buried in the earth.

The next step was to force water through the casing, which caused the earth in it to spurt out in a muddy stream. A smaller pipe was now pushed down inside the casing and, when the workmen pulled this smaller pipe out, they carefully took a sample of the dirt which clung to the pipe's bottom. This dirt they put in a glass bottle, labeled it, and stored it away.



Boring machine. The crew is fastening on a new length of casing. The pile driver can be seen just to the right of the casing itself.

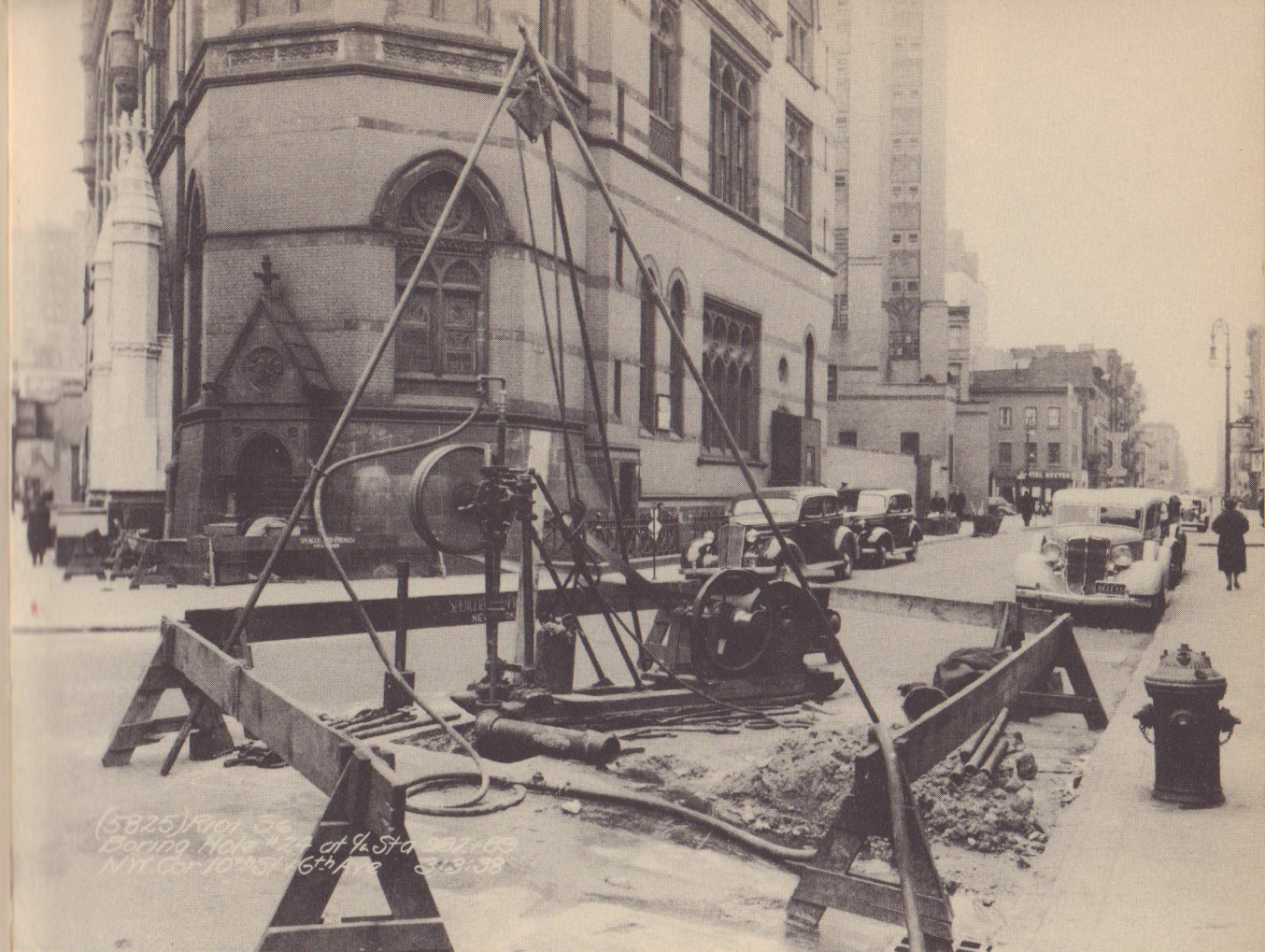
It was this they had been boring for—a handful of earth! Their job finished, they pulled the casing back out of the earth, dismantled the tripod, rolled the donkey engine onto the truck, put all their tools and pipes back, and drove away. The whole process had not taken three hours.

In the past thirteen years, while the building of New York City's new Independent Subway System has been going on, more than two thousand such borings have been made. Some may go down as much as sixty feet instead of thirty, depending on how deep the new subway is going to be at that point. Many of the borings run into solid rock, for there is much rock underlying New York City, and when that happens it may take days to finish a boring, instead of hours. The boring crews then use sharp diamond-pointed bits to burrow through the rock, instead of simple casing, and the bottles of samples contain pieces of rock instead of the coarse brown sand the workmen had found at Pitkin Avenue in Brooklyn.

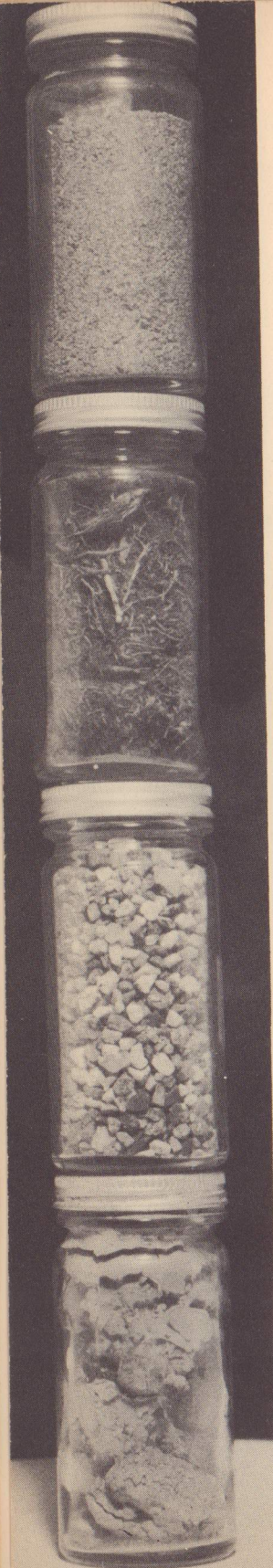
Of what use, one wonders, are these small bottles of earth?

In the huge offices of the Board of Transportation of the City of New York, engineers collect the bottles with their samples of sand or rock, and from them they are able to make detailed reports of the kind of underground excavation that will have to be done in the building of the new subway.

Since the subway engineers already know how deep the subway is going to be at certain points, it is obvious that much surveying, planning, designing and route selecting must have been undertaken before the borings themselves are made. And that is quite true. But before we proceed to a description of the work done in planning a subway, let us say a few words about subways in general.



Here a power borer is boring down through the casing, which is already in place. Earth samples will be brought up in the bottom end of the pipe which is being forced down through the casing. Not all boring machines are hand-operated; many of them are run by means of a flywheel attached by a belt to the engine, as in this picture.



Boring samples. These will give you an idea of the extraordinary variation in subsurface materials that subway builders have to cope with. At the top is a bottle of coarse sand. Next, a sample of peat, not often found in New York. Third from the top, gravel. And bottom, a sticky kind of mucky clay called "bull's liver," which is one of the hardest substances to work in, for it is very wet, very fine, and very hard to keep out of the structure. There are dozens of different kinds of material found while building a subway, of course. Various kinds of rock, in addition to these earth samples, are constantly being run into.

Although we are describing in this book the building of a particular subway in New York City, that does not mean that there are not other subways elsewhere in the world. Before the Independent System was started, New York City already had two other extensive subway routes. And these are not all. You will find in Chapter Ten brief descriptions of the more than a dozen other great subways of the world, in cities as far apart as London and Tokyo, Buenos Aires and Moscow.

However, since methods of subway construction are much the same all around the world, it is safe to take the building methods used in the construction of the Independent System as typical of subway work elsewhere. We are using it because it is the nearest to hand, and also the most complicated and therefore the most interesting. It is, in fact, one of the greatest networks of subway tracks ever built.

This Independent System of New York's is 57 miles long, and it has been in the process of construction ever since 1925. Its latest link, under Sixth Avenue, will not be finished until 1941—and it is the most difficult job of subway building ever attempted anywhere.

PLANNING A SUBWAY

But how actually does the Board of Transportation go about the planning of a new subway, before even the borings have been made?

In the first place, the sections of the city where the subway is to go must be decided upon. Do certain neighborhoods really need a subway? Are there enough people there already to make the subway pay? Or will the new route bring a sufficient number of new inhabitants to live there?

The Board usually decides these points after holding many public hearings, which it must hold under the provisions of the rapid transit law of New York State. At these hearings, citizens are given a chance to tell why their section of the city needs a subway.

After much argument pro and con, but mostly pro, the Board of Transportation adopts a tentative route. The plan which they adopted for the Independent Subway reaches many neighborhoods which never had subways before.

As soon as the Board adopts a tentative route, the Real Estate Division of the Board gets to work. This is a highly important step, for the city cannot build a subway along any street in New York unless the owners of 51 per cent of the *assessed valuation* of the property along that street agree to it. Assessed valuation is the money value at which each piece of property is rated by the city Tax Department in order to fix the amount of taxes to be paid on it.

Usually there is little difficulty in getting the owners of a majority of the assessed valuation to agree to the building of a subway, for the subway makes the neighborhood more accessible, and, therefore, increases its value.

At this point the Board is faced with a new and difficult problem. The State rapid transit law commands that the Board make an estimate, based on careful statistical studies, of the income it expects to earn on five-cent fares each year for the first ten years of city operation. In New York the fare charged on all rapid transit lines is fixed by law at five cents, no matter how far one rides. So experts are set to work figuring out as best they can how fast the neighborhoods along the new subway will grow. On the basis of past experience, these experts are able to make amazingly accurate estimates of the subway traffic.



Here is where interested citizens, representatives of citizens' groups, real estate operators, and any one who has any interest in the building of a new subway, come to put forth their particular views on the matter. Members of the Board sit up at the far end of the room, listening and answering questions. Hearings are also held here about contracts and other technical matters.

When they have compiled their figures, and the route plan of the new line has been roughly drawn up by draftsmen employed by the Board, all this data goes to another city organization—the Board of Estimate. This Board has the responsibility of financing the building of the subway. And a real job they have on their hands, for the new Independent System has cost the city over \$700,000,000! Of course, this sum did not have to be raised all at once, but rather over the whole period of thirteen years that the subway has been in the process of construction.

Now the route plan, the traffic estimates, the property owners' permissions, and the financing are arranged for. And yet there are still many months of hard work to be done before the first excavating can be begun. Next come the borings, the surveying, and the designing.

CHAPTER TWO

THE BLUEPRINTS

EVEN the preliminary work for the building of a new subway is not all done at one time. The city could not possibly afford to have the whole 57 miles of new route under construction at once. So the Board of Transportation chooses the area of the city that needs the subway most and starts work on that. Perhaps it is only five miles long, perhaps ten.

First, then, the borings we have described earlier are made along this section of the new route, and the samples are collected and sent to the engineers of the Board. These borings are not made by men working directly for the Board, however. The Board lets out contracts for the borings to contractors who have the machinery for the work, and they hire the workmen.

Even before the borings, sometimes, comes the big job of surveying, which is done by the Board's own surveyors.

Probably everyone has seen a surveyor at work somewhere, measuring property lines, preparing data for the laying of sewers or water mains, or drawing lines preparatory to the widening of streets.

Most of the surveyors who work for the Board of Transportation are young men. They go out into the neighborhood where the new line is to be built, and get to work plotting out a *base line*, from which all future measurements for the subway will be taken.

This base line is an imaginary line of known length and known angles (the angles are called *traverses*) which the surveyors run along the center of both sidewalks of a street.

What the surveyors do is this. First they establish a known point in the sidewalk, usually just where the new subway is to begin, and chisel a deep "X" in the sidewalk, to mark the exact point. Then they measure off a hundred feet along the street with a metal tape measure and mark another "X". This distance is called a *station*. They repeat, measuring off another hundred feet to station number 3, mark it with their chisels, and go on to the next station.

To make it absolutely accurate, they use a *level*, which measures the *grade*—how much uphill or downhill the street goes, and a *transit*, which measures even the slightest curve in the street. These instruments are like small telescopes on tripods.

If the subway has to go around a curve, surveyors can get accurate information with their transits as to the exact radius of the curve the subway must follow.

Once the surveyors have laid down their imaginary base line, they mark on their maps every single thing along the way that might cause trouble when digging operations start. They describe every building along the street. They mark every opening in the sidewalk. These obstructions include stairways going down cellar; basements which lie under the sidewalk and are usually used for storing coal; manholes for coal shutes; light poles; telegraph boxes for police and fire alarms, and various other things.

Finally the surveyors have to find and mark on their maps every pipe, every conduit, every wire, and every tube under the street surface. They get all this information, including accurate maps of the route of each



Here a surveyor is checking his base line with a transit. The board in front of him with the figures on it contains the number of the surveyor's "station" which he is checking.

one of these *subsurface structures*, as they are called, from the companies which own them—telephone companies, water companies, gas companies, and the like. Subsurface structures under streets in New York include some or all of the following:

Gas mains.

Water mains, including special high-pressure mains for fire hydrants.

Sewers.

Wires of all kinds, such as telephone, telegraph, electric power and light, special street light wiring, traffic signal, police and alarm systems, all of which are carried through special *conduits* in New York City. In a large part of the city no wires are above ground on poles. They are all underground in special pipes, or conduits, of their own.

U. S. Mail ducts, which in Manhattan are pneumatic tubes through which bundles of letters are rapidly "shot" from postal station to postal station by air pressure.

Steam mains, which carry live steam for heating from steam supply plants in some areas of the city to certain large apartment houses and business buildings which do not have furnace systems of their own. These mains are found only in crowded areas of Manhattan.

Underground trolley wires. In a large part of New York all trolley wires are laid underground between the trolley car tracks.

Bridge or elevated railway supports, which all have deep underground foundations; and occasionally monuments placed in the middle of parks or squares under which the subway must go.

Now the surveyors have a complete record of these subsurface structures on their base line maps. The samples of earth from the borings are in hand, and here is the final step before actual construction begins:



"Chaining"—the technical name for the measuring of the space between stations with a special metal tape measure. The surveyors must measure the distances with absolute accuracy.



Surveyors' stations in two very different parts of town. One in a slum area up in Harlem (top) and another in a peaceful section along Central Park.



The Design Division of the Board of Transportation takes over all the information that has been so painstakingly collected. This division is one of five major branches of the Board; the others are the Track Division, the Equipment and Operation Division, the Station Finish Division, and the Field Division, of which the surveyors are a part, and which supervises construction work on the spot. In addition to these there is the Specifications Division, a smaller unit, which prepares the specifications and writes the contracts for the various subway construction sections.

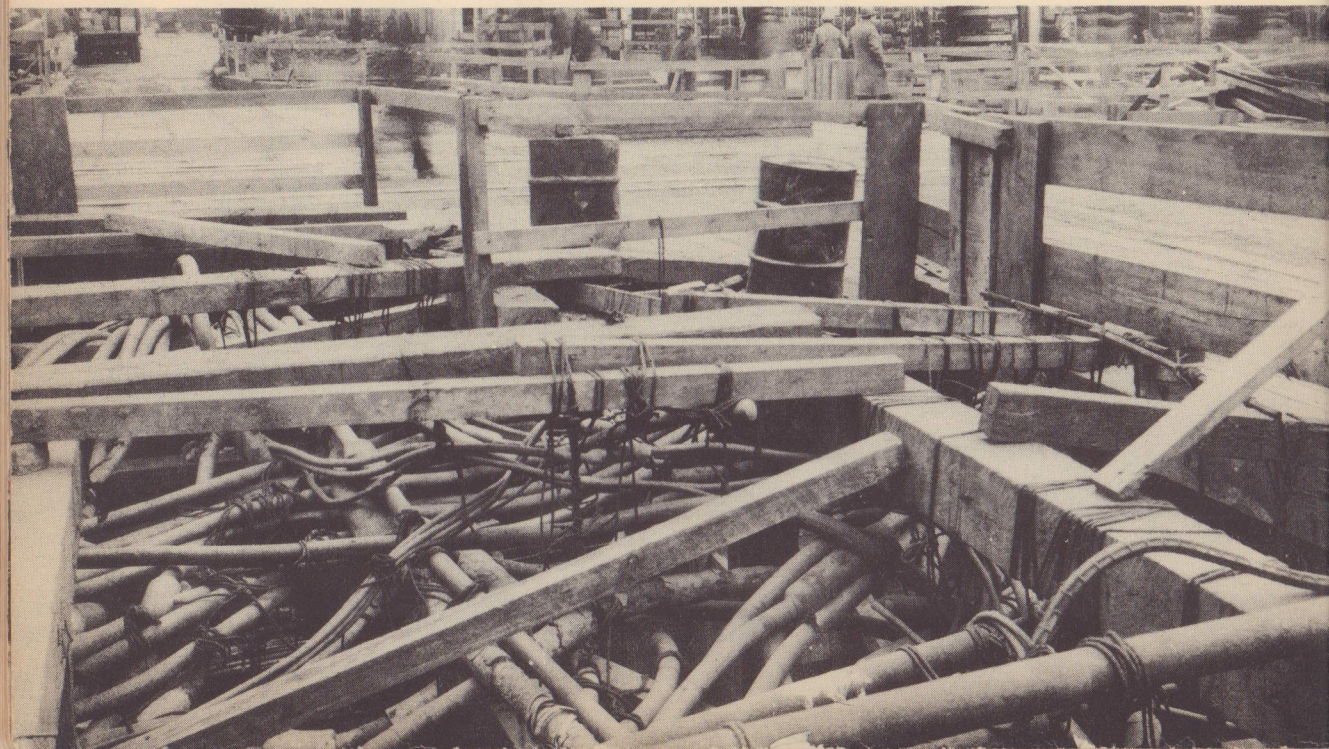
In the Design Division, then, all the data collected is divided into sections of the route, usually about half a mile long. Squads of twelve men take all the information about their particular half-mile of route—and get to work on *contract drawings* of the subway construction.

These contract drawings are by no means the final working plans—they will come later. What the squad of twelve men now work on are preliminary drawings of the hundred and one different parts of subway design which the contractors, who will do the construction, must use as a means of estimating their costs of labor and materials. As you can see from the picture of the profile and plan of a half-mile section of the subway, these drawings themselves are extremely complicated affairs—but they are nothing to the working blueprints which come later!

The squads of twelve men are made up of a squad leader, an assistant leader, two men who check the drawings, two designers, two structural steel draftsmen, and four junior draftsmen who make tracings of the original designs. It takes these twelve men *from four to six months* of untiring, constant work over their drafting boards to complete the preliminary contract drawings for a single half-mile section of subway!



Here you can see, very faintly, to the left of the chalked number, an "X" in the sidewalk, which the surveyors have chiselled there. Below— This gives something of an idea of the complicated mass of pipes, tubes and conduits that a surveyor must have knowledge of in making his maps.



For a simple subway section, a minimum of forty contract drawings are required. But for a really difficult job, such as any section along the new Sixth Avenue extension of the Independent Subway in Manhattan, well over a hundred drawings are needed.

When finished, these drawings are printed and bound up into a book, one for each section. The contractors who are interested in bidding on the job must buy this book at \$5.00 a copy.

But the contract drawings alone are by no means sufficient to inform the contractor of all the details of his job. In addition to these drawings, the same squad of twelve men has drawn up careful estimates of the quantities of every kind of work to be done by the contractor in building this particular piece of subway. These estimates are printed in a separate book, which the contractor must also buy, at a cost of \$1.00.

Every conceivable kind of data which the contractor must know about is included. Estimates of the number of cubic yards of earth or rock to be excavated; the number of tons of steel girders to be used; the number of cubic yards of concrete needed; a careful list of each and every building along the route which will have to be *underpinned*—underpinning will be explained in the next chapter—and anywhere up to 250 other separate items, which go to the making of a modern subway—all are to be found in these books, which carry the odd name of "Invitations to Contractors."

Men in the Specifications Division work closely with the squads who are designing the subway; it is their job to specify, very minutely and accurately, the exact kind of materials which are to be used by the contractor in building the subways. The kind of steel; the correct formula for the concrete; the size and kind of pipes—all these matters are decided upon, on the basis of past experience which has taught them what is best for each kind of subway work, by the members of the Specifications Division.



Drafting room. It is in rooms like this that the data compiled by the surveyors is gradually, carefully worked into plans from which the subway itself will eventually be built.

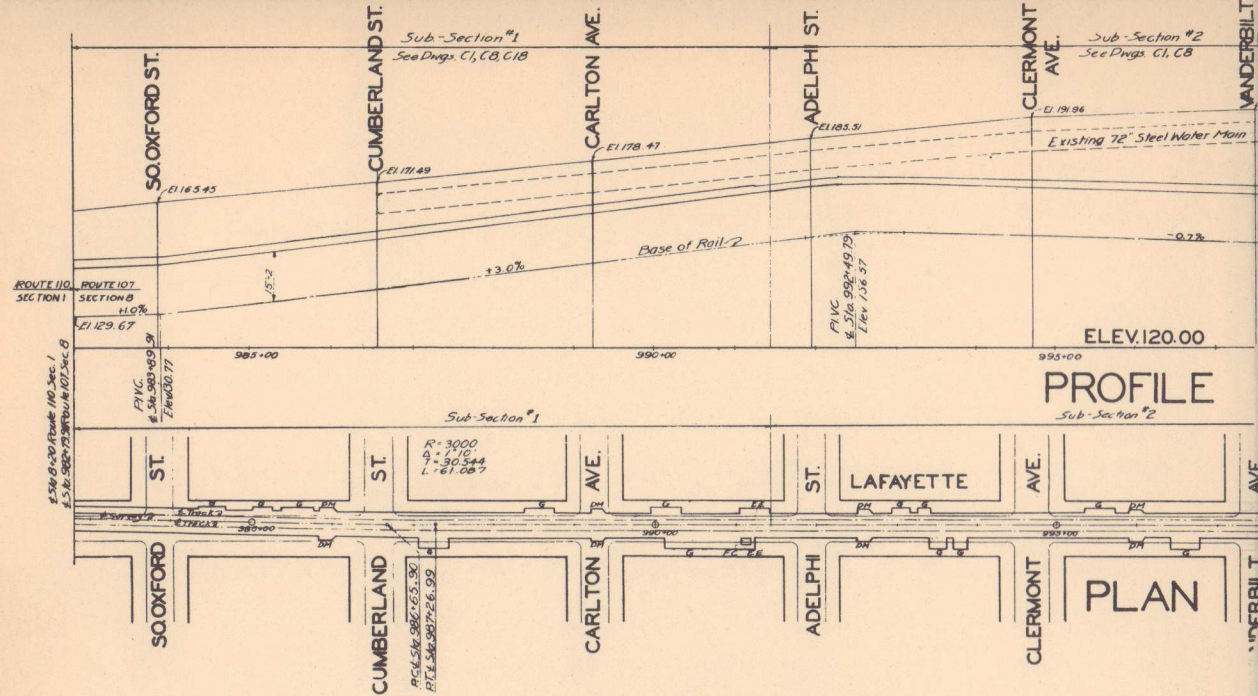
The contract drawings, estimates and specifications of which we are talking now are only for the actual building of the subway structure itself. They do not include the tracks, the signal equipment, the rolling stock (cars), or the final station finish. These parts of the work are quite separate from the structural part of the task, and different engineers design the different parts, different contracts are let out on bids to different, specializing contractors, and the work, of course, has to be done at different times.

Work on the designing for the tracks and for signal equipment proceeds in the divisions of the Board which do that kind of work just as soon as the structural division has prepared the drawings of the *grade* and the *alignment* of the new route. Grade is the pattern of the subway measured vertically: that is, how much level track; how much track going up or down hill; and exactly what degrees of steepness going up or down hill the grades are. Alignment is the actual horizontal pattern of the new route, measured in stretches of straight track and in the curves—and the exact degree of each curve—which the subway will follow.

However, these divisions complete their work later. Now everything is ready for the contractors on the actual construction part of the job.

The Board of Transportation advertises for bids on the building of this particular section of subway. Perhaps eight or ten, perhaps more, contractors will bid on the job. In practically every case the one who submits the lowest total bid, and who can prove himself financially and professionally responsible, gets the award of the contract.

Then the proposed contract and the bid are presented to the Board of Estimate, which approves them, and appropriates funds to pay for the work as it progresses—and at last the real work of building starts!

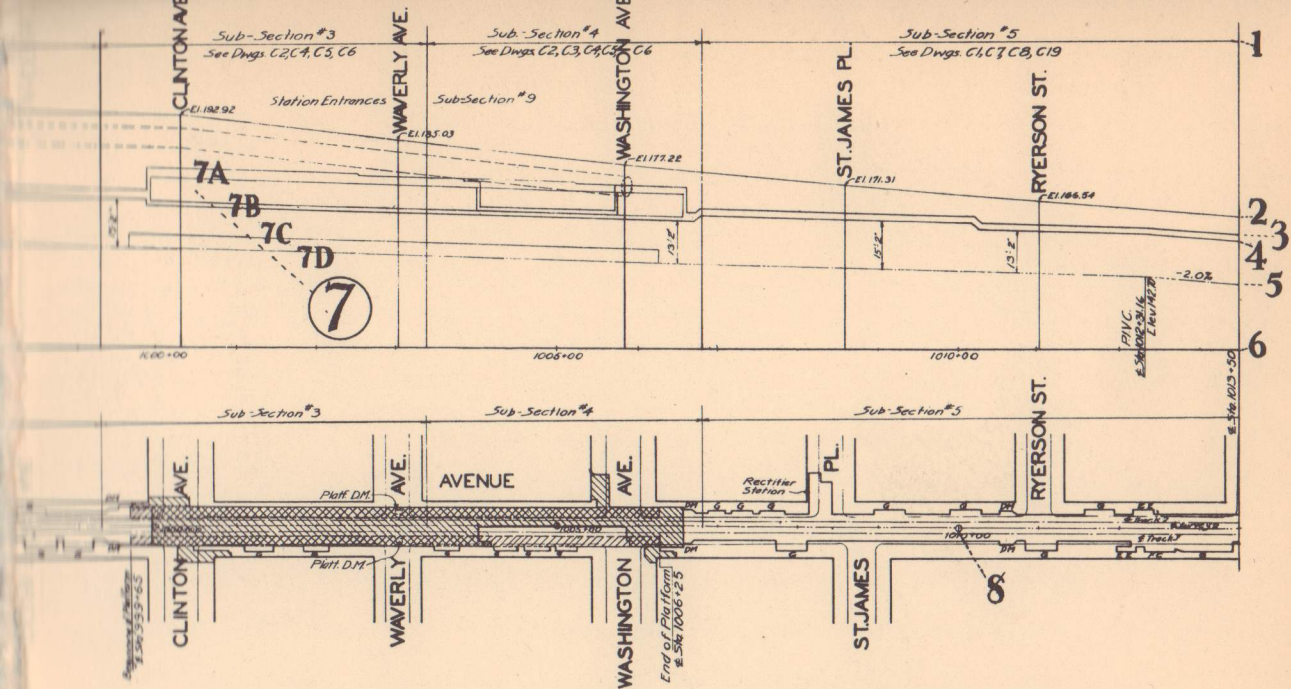


PROFILE AND PLAN

This is part of a rough general drawing of a complete section of subway, and is the first sketch in any book of contract drawings. This particular section was actually nearly twice as long as the part shown here. The "profile" is the vertical section of the route, showing how high or how low, and what grades between high and low, there will be along the line. The "plan" is the horizontal view of the subway, the view you would get looking down at the route of the subway from a height.

There are a great many things on this drawing that you can figure out for yourself, and some that you cannot. The latter are for the most part mathematical or technical data which the surveyors and engineers need for their work—material which cannot be described in this book because of lack of space.

1. Guide Line, used only to indicate subsection divisions of the whole section.
2. Street Line. This is the actual curve of the street level.
3. "Roof" of the subway (outside surface).
4. "Ceiling" of the subway (inside surface).
5. Base of Rail, meaning the actual bottom of the rails as laid, including ties. The concrete foundation of the structure, or "invert" is below base of rail.



6. Elevation line. This line in most cases reads 100, instead of 120. But this particular piece of subway lies higher in the ground than most, and the ground itself is higher than usual. So in order to make the elevation line conveniently near the structure of the subway, the engineers arbitrarily chose the figure 120. And another strange thing is that an elevation figure of 100 actually is "zero" elevation, or mean high water level of the ocean. In every case the 100 figure is used instead of zero, because if zero was used, and the subway structure went below mean high water level, the engineers would be running into minus quantities of elevation, which would be extremely confusing and might lead to many errors. Therefore 100 is arbitrarily added to the zero elevation. Subways very rarely are built 100 feet below water level, not even in tunnels under rivers.
7. Here is the rough plan of a station. 7a is the roof of the mezzanine, or station area over the tracks and below the street where passengers can cross over from uptown to downtown tracks. 7b is the floor of the mezzanine and the roof of the subway itself. 7c is the station platform, four feet above 7d, the subway tracks themselves.
8. A station mark—not a subway station such as is sketched in under point 7, but a "surveyor's" station, such as is described on page 23.

CHAPTER THREE

BEFORE EXCAVATION

UNTIL now all the work on the new subway route has been done by the Board of Transportation, except the borings which were done by private contractors. Now, however, the Board takes on a purely supervisory role. Its inspectors and engineers go into the field where the construction contractor is at work and examine, test and approve every type of material to be used, every method of construction, and all other details. But they do none of the actual building, for that now becomes the job of the company which has won the contract for the building of a section of the new subway.

Several important tasks must be done by this company before it can begin actual excavation. Out of the thirty months or thereabouts it is allowed for actual construction, the contractor will spend from one to four months on these preliminary tasks.

BUILDING EXAMINATIONS

Every single building along the street where excavation is to take place must be carefully examined by the contracting company's engineers, an engineer of the Board of Transportation, and the owner of the property or his agent.



Although this a pretty solid looking brick wall, there is a big crack in it from top to bottom; and building examiners take great care to record in their reports exactly how wide the crack is and even, as in this case, take a picture of it. If the owner should complain that the subway excavation caused it, this picture will prove to him that it was there before the builders ever started digging.

Often the construction of a subway takes up a space, under ground, which runs clear across the street from building line to building line. Sometimes it even runs underneath the buildings themselves. When an enormous trench, thirty to sixty feet deep or more, is dug close to the foundations of these buildings, there is plenty of chance for the foundations to begin to "settle" or slip into the excavation. A settling of only three or four inches may cause a ceiling in the house to fall, or a dangerous and ugly crack to appear in the walls.

A property owner may sue the contractor for such damage to his building—and this is the reason for the very detailed building examinations which must be made to record every existing crack, looseness, and other defect in the building *before* the subway excavation is made. In case of a dispute in which the property owner claims that damage was done to his building by the digging for the subway, these records will prove whether this is true or not. The Board of Transportation engineers, who were present when the building examination was done, sometimes serve as umpires between the contractor and the property owner, and decide whether additional damage has been caused to the building.

FIELD OFFICES AND SHOPS

While these examinations are being made, the contractor is setting up his field offices near the scene of the job. It is here that his own engineers and other representatives do the actual supervision and the management of the work. For these offices he rents space in nearby buildings—but there is another kind of field office which presents a real building proposition.

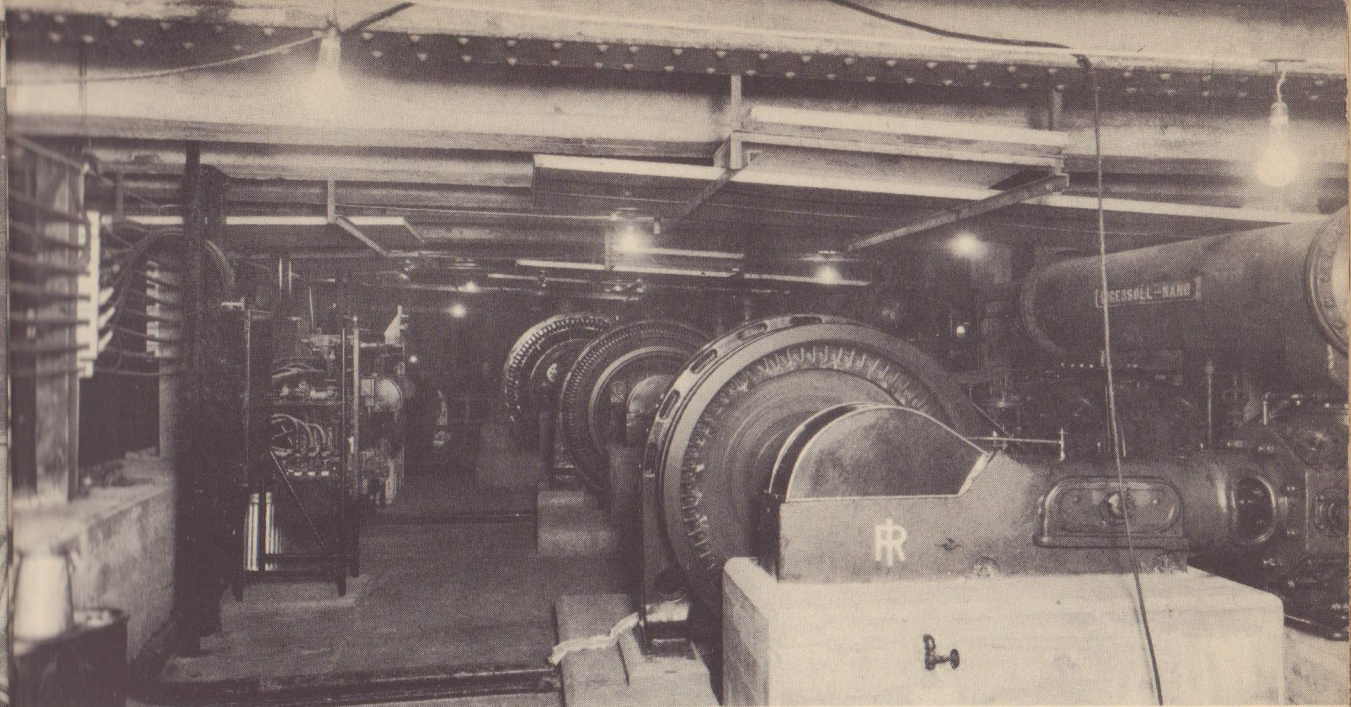
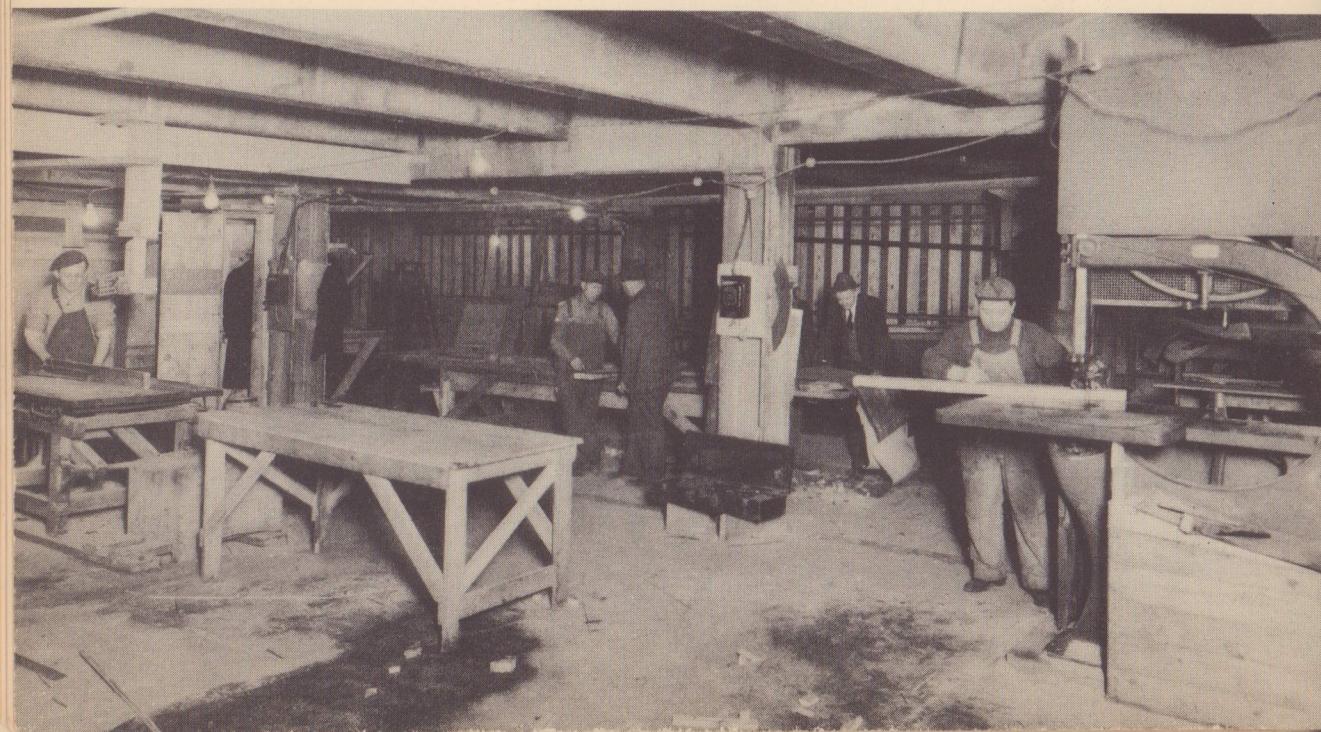


Field offices and shops right on the spot where subway work is being done. The clinic is for workmen who get hurt on the job. To the right is a low building put up by the contractor for the use of the Board of Transportation engineers and field draftsmen. The huge crane in the background lets down its hook to the bottom of a huge shaft, where excavated material is brought in buckets to be hoisted to the surface. There is a picture of the bottom of the shaft on page 104, bottom.

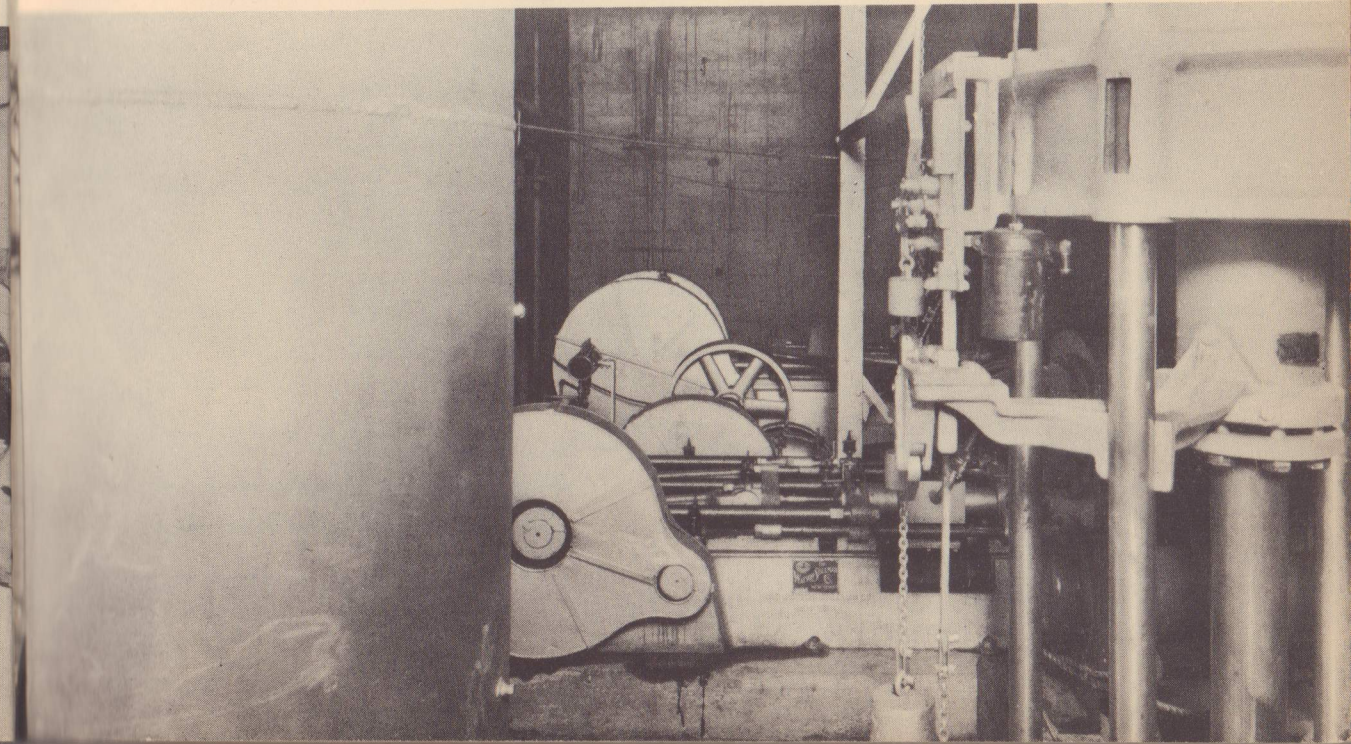


2555) R101 S10
6th Ave. Cut bet. 46th & 47th Sts.
Contractor's Blacksmith Shop.
3:16:37

Sometimes, if there is not room on the surface, the contractors put their shops underground, right alongside the subway excavation. Above is an underground blacksmith shop, with piles of rock bits ("jack bits") in the foreground; below is a carpenter shop, installed in a section of subway previously finished.



Contractors' shops frequently include heavy pumping machinery, especially if their job is tunneling or blasting. Above are three huge air-compressor pumps, which furnish air for power drills and the like, and also for the pressure in "shield tunneling" (see Chapter 6). Below are hydraulic pumps, which furnish water under pressure for working hydraulic tools of various kinds.



Somewhere along the line of construction the contractor has to build a series of temporary structures which contain blacksmithing shops, carpenter shops, an emergency hospital for injured workers, and machine shops where tools and special equipment are repaired. These buildings are usually made either of corrugated iron, or of a light wooden sheathing. After the job is done, they will be taken down and carted away, if salvageable.

BLASTING PREPARATIONS

If the section to be dug contains rock that will have to be blasted out, the construction outfit has to put up window protectors on all display windows in stores, and even in upstairs offices where the windows are very large. All large expanses of glass along the section to be blasted must be so protected, and also similar windows in buildings down the side streets for several hundred feet: for a good, healthy blast of dynamite which will break up and loosen four or five feet of solid rock in the subway excavation will also rock the buildings for quite a distance around, and smash their unprotected windows with the vibrations of the blast.

A wooden support is firmly fastened in the middle of a piece of plate glass with wire braces fastened at the other end to the four corners of the window. This support actually serves to divide the big piece into four little pieces, so that the vibrations caused by an explosion will shake only a quarter section rather than the whole piece of glass. And, since the smaller the piece of glass, the more vibration will be needed to break it, the protectors reduce the possibility of breakage by 400 per cent. These window protectors are sometimes called "spiders."



A window protector fastened on a big piece of plate glass. The engineers have figured out that the smaller windows in this building will not need protection, but that the big one might smash without it.



A dynamite building (above). This picture gives you some idea of the street congestion caused by building a subway in a busy city. Below is the simplest kind of gas-bypassing: a small pipe is laid in the gutter, and no ditch for it need be dug. Later it will be covered with a wooden platform (see next picture).



Protectors are not needed if the blasting is done in deep tunnels, where the surrounding earth or rock absorbs most of the shock. Nor are they required in certain kinds of difficult blasting near the surface, where very small charges of dynamite are used. But in regular blasting all large windows must be protected.

Of course, before doing any blasting, the contractor must get permits from various departments of the city—especially the fire department—to store dynamite along the route of construction. You have seen little white-painted, corrugated iron buildings half on the sidewalks, half in the street, bearing the word “Dynamite” in large red letters on all four sides, as in the picture on this page. In these buildings just enough dynamite for one day’s work is kept, carefully cushioned with sawdust and other substances from the possibility of jarring or shock.

BYPASSING

The final and most important job to be done before actual excavation is the *bypassing* of the gas mains.

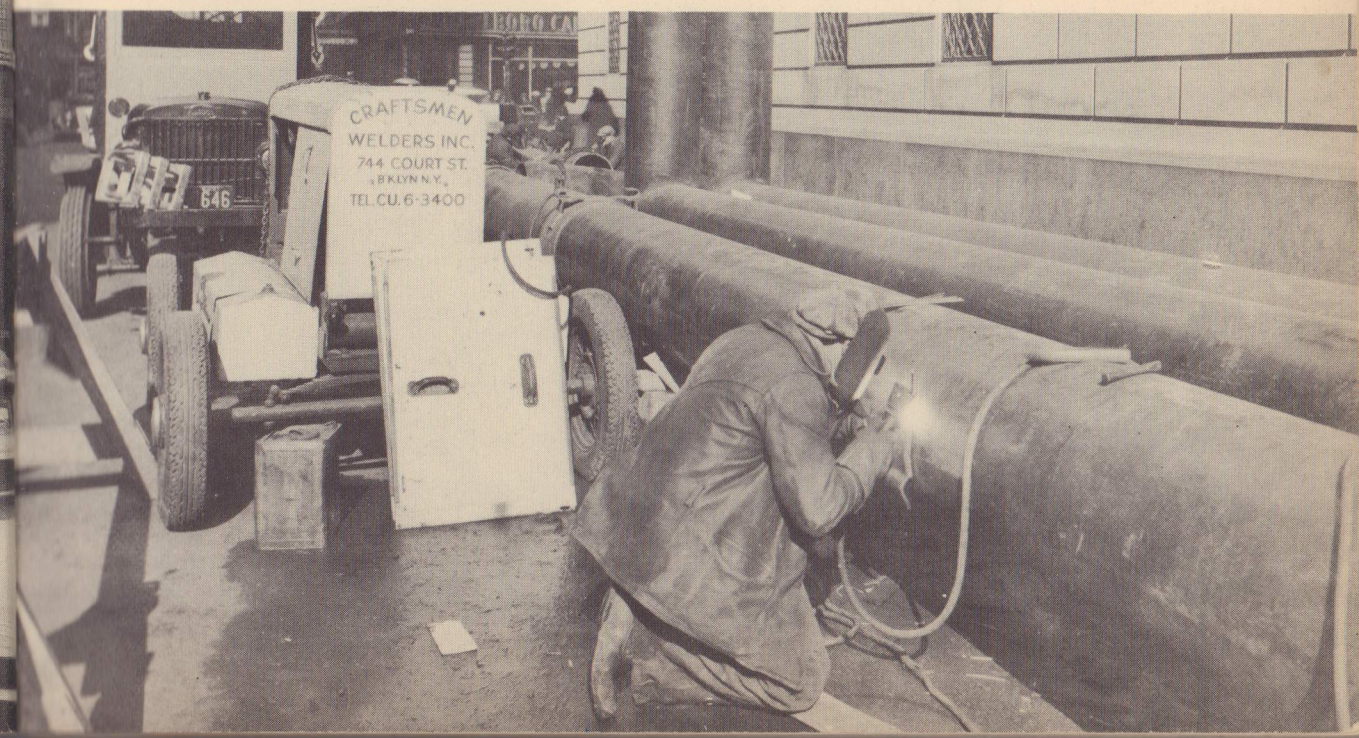
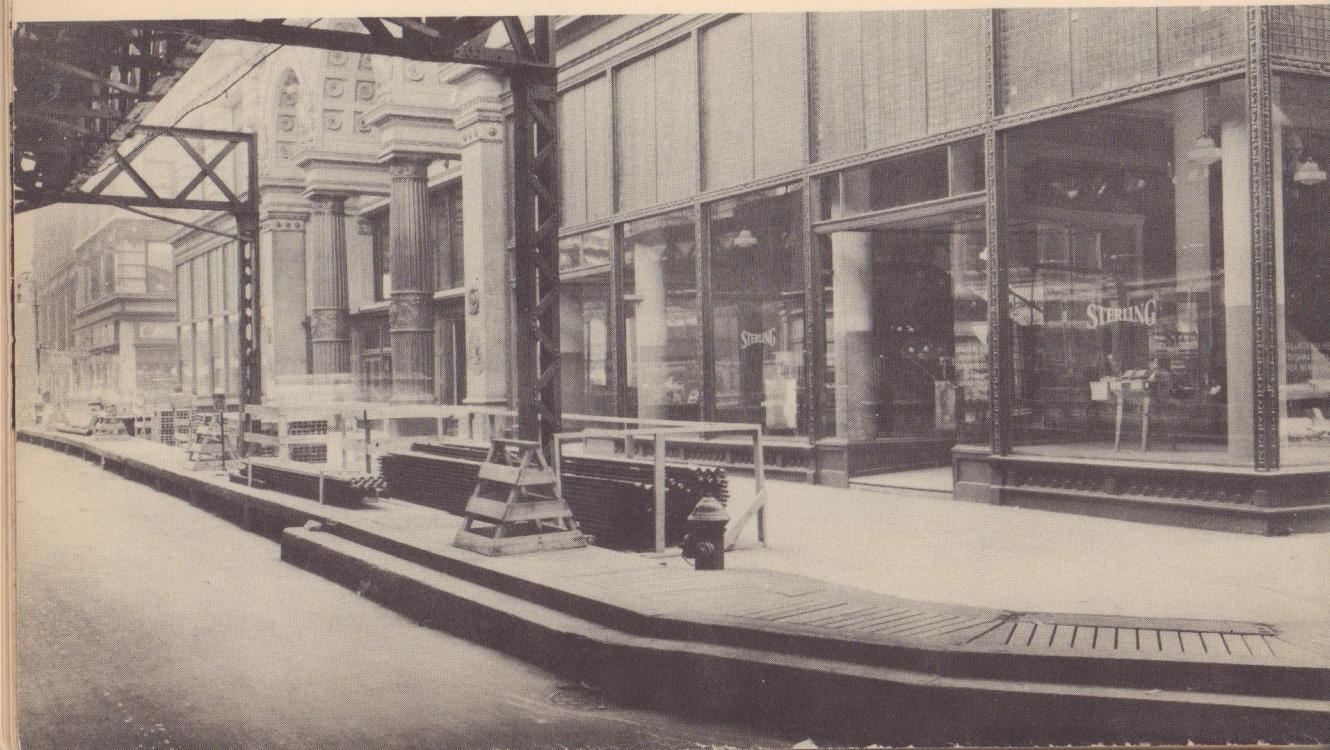
In all big cities the streets are lined with pipes, lying quite near the surface, which carry gas to office buildings and homes, lofts and apartment houses. Gas is extremely inflammable, as you know. So the fire department requires that, where subway construction is under way, the gas must be rerouted to run through temporary mains which lie *on the surface* of the street. There is too much chance that during excavation, even where there is no blasting, a steam shovel might run into a gas main under ground, or a drilling outfit might accidentally break into the main, thus causing a leak or, even worse, a serious fire or explosion.



Above, preparations are being made for the laying of a much larger pipe. The pipes themselves can be seen on the sidewalk. Below—Now the gutter bypass is all finished, and the wooden platform over the pipe is in place. People have to go two steps up to climb over the pipe!



Making a connection between an old gas-main and a gas bypass. To the left the pipe goes several feet underground and connects with the permanent main; to the right is the bypass, through which the gas will run from this point while the subway is being built. Below—Welders are welding sections of pipe together so that there can be no gas leakage once gas is passing through the pipe.



So special pipes are laid, ranging from five inches and up in diameter (depending on the size of the existing gas main under ground) along the gutters of the streets. If the pipes are small, they can just be laid in the gutter without further work. But if they are large, a crew of excavation men dig a trench in the gutter deep enough to keep the pipe from being an obstruction.

These pipes must be laid along both sides of a street. Houses on both sides of the street must have their gas, and, since no live gas is allowed to cross under the street where subway work is being done, these special gutter bypasses must be laid, dividing the flow of gas in equal halves—half for one side, and half for the other.

After the temporary gas bypasses are laid, the workmen, with the supervision and assistance of the gas company's own men, very carefully open the old main under ground, make a connection with the temporary main, and let gas run, at lower pressure, through both old and new pipes for a while. It is easy to imagine the care with which they make this connection—for gas is never shut off during the process! It takes real science to do the job safely.

When the connection is made and gas is running through both series of pipes, the men arrange with the owner of each and every building along the street to cut off his gas for an hour or two while his gas connection is transferred from the old main into the new and temporary bypass.

Many of the streets crossing the line of subway construction have huge gas mains of their own, running perhaps from a gas-making plant away on the west side, across to a neighborhood far on the east side of town. In such cases a huge *overhead bypass* is built, with strong towers to hold the pipes at least fourteen feet above the street. The

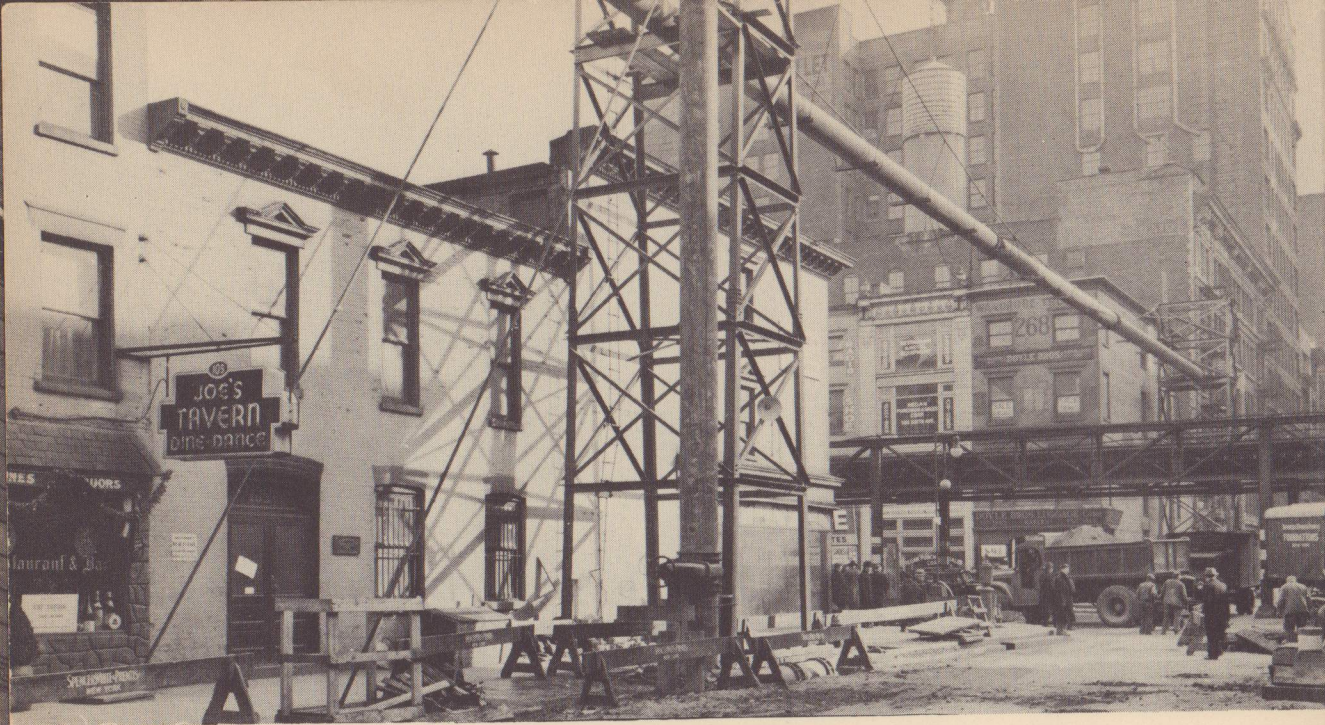


Lifting an overhead bypass pipe into place. The crane holds it up while men (not visible in the picture) make it secure to further sections of the pipe.

gas in this crosstown main is rerouted into the overhead bypass and then led down into the ground again on the other side of the digging area.

38-17880

With the finishing of the bypassing job, the major preliminary work is completed. Back in the offices of the contractor, final arrangements have been made for getting the labor and machinery needed, and now the actual digging begins.



A completed overhead bypass. Below is a peculiar structure called a steel gas box. This is an extremely expensive gas pipe, which is used on those very rare occasions when it is absolutely necessary that the gas pipe be routed under a section of street where construction is being done. This practically never happens.



CHAPTER FOUR

THE EXCAVATION: CUT-AND-COVER

Now the first crew of excavators starts digging. Where it is possible to dig right from the surface down to the bottom, the "cut-and-cover" method is used. This means that sections of the street no more than a block long are opened and as soon as possible bridged over with temporary steel and wood structures, so that traffic can continue along the street unobstructed. Never more than a third of the cross area of a street is cut into at one time, either, thus allowing traffic to continue down the other two-thirds while excavation is under way. When tunnels are dug far beneath the street surface, no decking is used, of course, for the street is not disturbed during tunneling.

Air-power drills, with chisel-shaped cutters, cut the asphalt surface of the street. These drills are supplied with air pressure by a small portable air-compressor unit from which air is taken to the machines through heavy rubber hoses.

After the asphalt is removed, the workmen change the cutting edge in the drill to a sharp-pointed, four-sided cutter called a concrete breaker, or *bull point*. The bull point bores down into the concrete base of the pavement and breaks it away in large hunks.

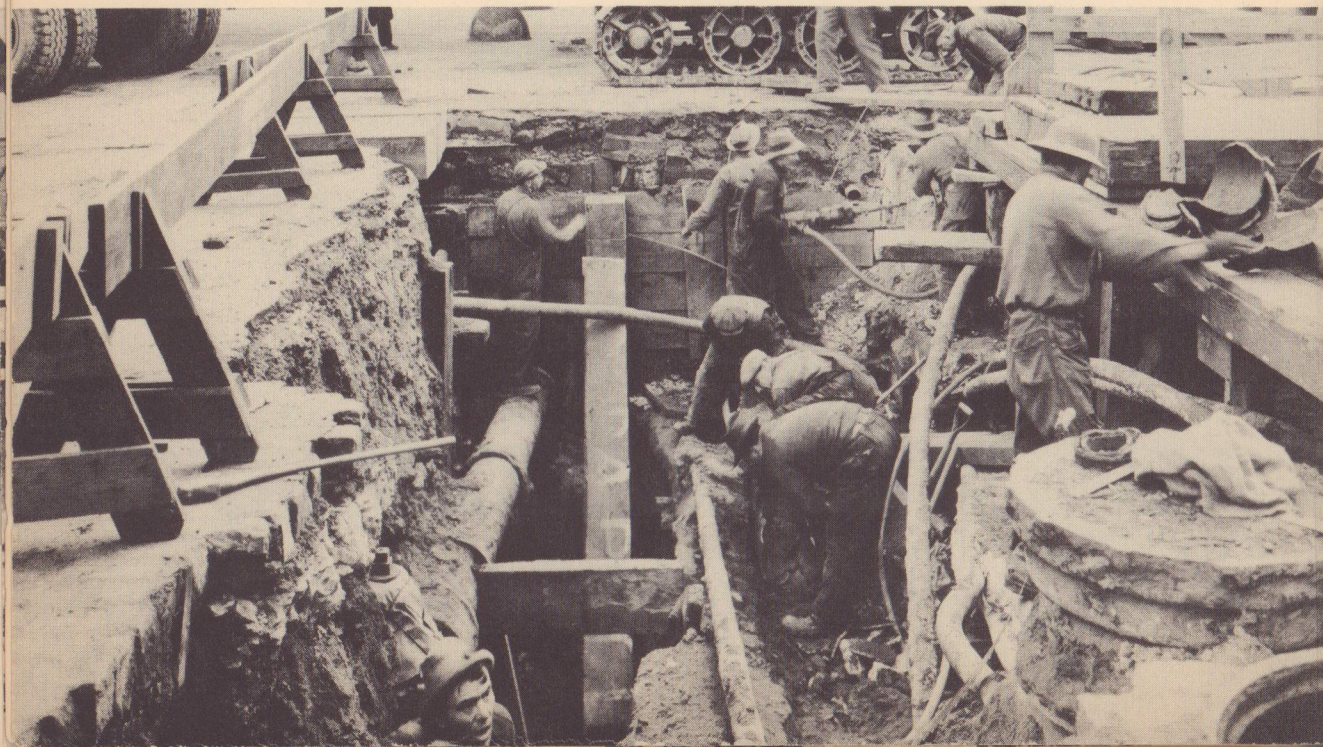
All the asphalt and concrete thus removed is shoveled into trucks either by hand or by regular "steam shovels" and is carted away to a



Breaking up the street surface, preparatory to excavation. Here the shovel is picking up the large hunks of asphalt and concrete previously broken up by workers with their air-power drills.



Digging down! Above the excavation seems to be fairly clear of subsurface structures—just a pipe or so. Notice the feet of the curious bystanders. The picture below shows what excavation is like when the subsurface structures are thick in the ground. One has to dig very carefully in this kind of excavation, in order not to smash the pipes.



dumping ground sometimes miles distant from the scene of the digging. The word "steam shovel" no longer accurately describes the modern power shovel used by builders, since steam power is practically never used any more. Gasoline or Diesel engines do most of the work, and occasionally you will find an electrically operated shovel noiselessly scooping up the excavated material.

Once the paving is removed, crews of pick-and-shovel men begin digging out the earth underneath the paving. And here the fun begins! For in the earth, between two and ten feet below the surface, lies the great mass of subsurface structures which we described as having been recorded on the surveyors' original baseline drawings. None of these structures must be damaged in any way while excavation is going on. So this part of the work requires a good deal of time and extreme care.

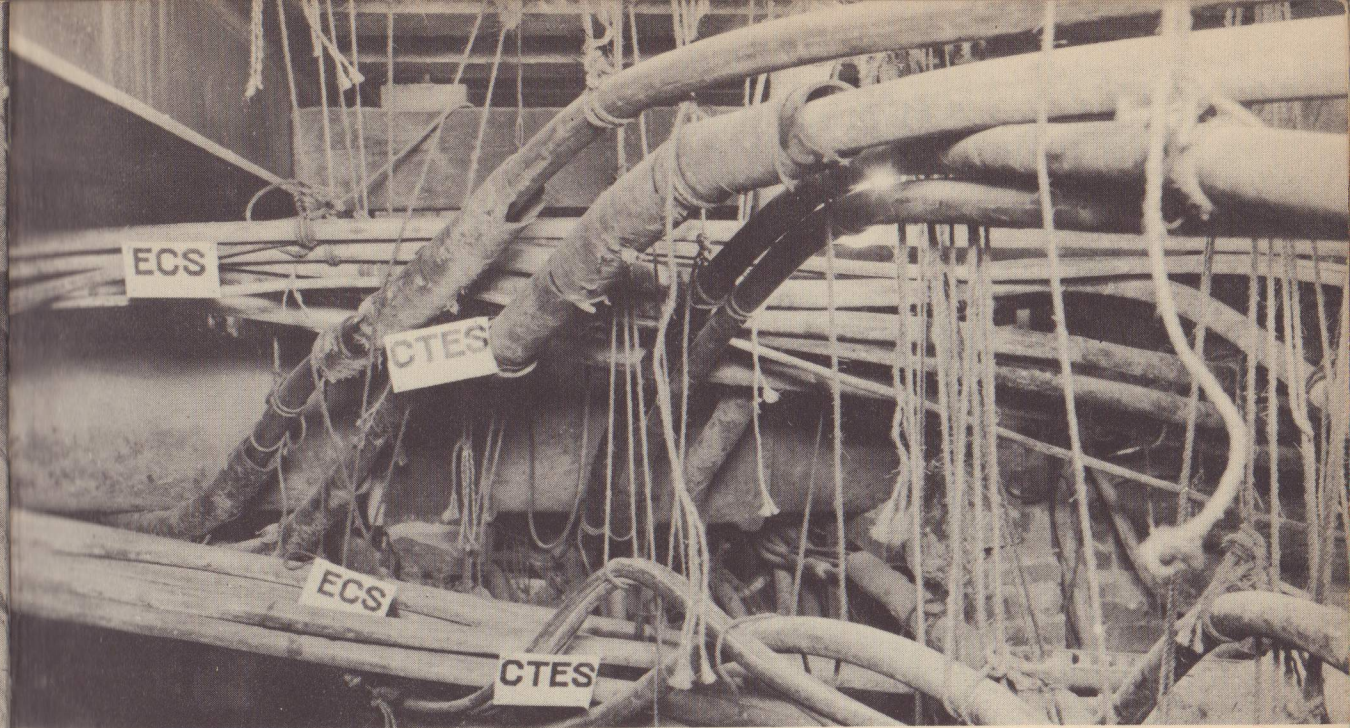
SUBSURFACE STRUCTURES

Every pipe, wire, cable, tube, duct and conduit is of course known to the contractor and his foreman, together with the approximate location of each item. As digging progresses, the foreman of the excavating crew, together with the Board of Transportation field engineer, watch out for the various pipes and cables. As each one appears, it is carefully dug around and, if possible, supported in place by steel or hemp ropes, called *hangars*, which are suspended from wooden or steel cross-beams laid on the open street.

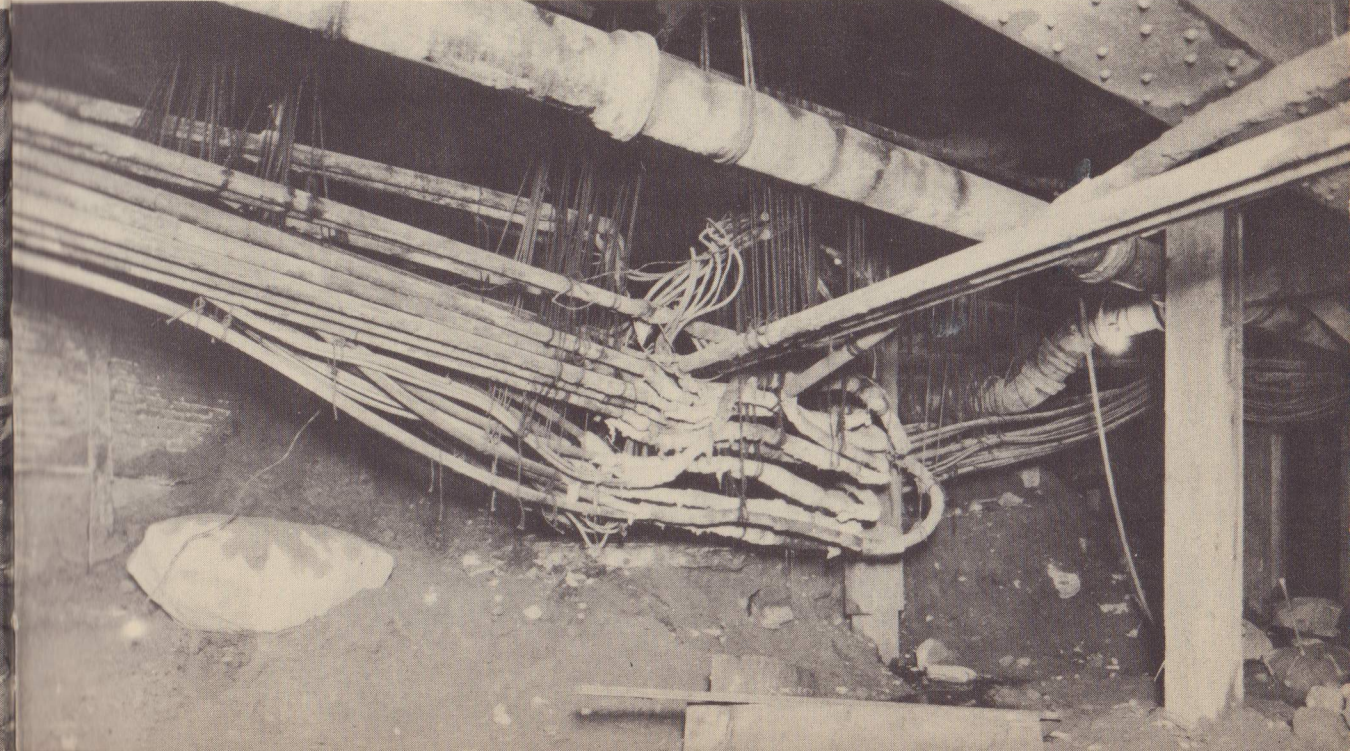
Many of the subsurface structures, however, cannot be supported in this way. Great blocks of cables encased in concrete will be found, some of them six feet square or more. Inside these solid blocks hundreds of wire cables have been laid, each in its separate tile duct, and



Subsurface structures. Above is a duct-bank which has been broken apart, and each pipe separately cared for. Below—A bank of ducts left intact, and suspended from the decking as it crosses inside the subway structure.



Closeup of a seemingly inextricable tangle of pipes. The letters indicate the names of the companies who own the pipes. Below—A view underground of the subsurface structures suspended with rope hangars from the decking.





Three men and some pipes! A new gas main is being installed.



Above—The subsurface structures are in the process of being cared for. They are not all fixed as yet. In the picture below an engineer is taking data on some important pipe. The scene is the same as in the picture above—as you will see if you look closely. Note the tips of the children's feet at the top of the bottom picture.



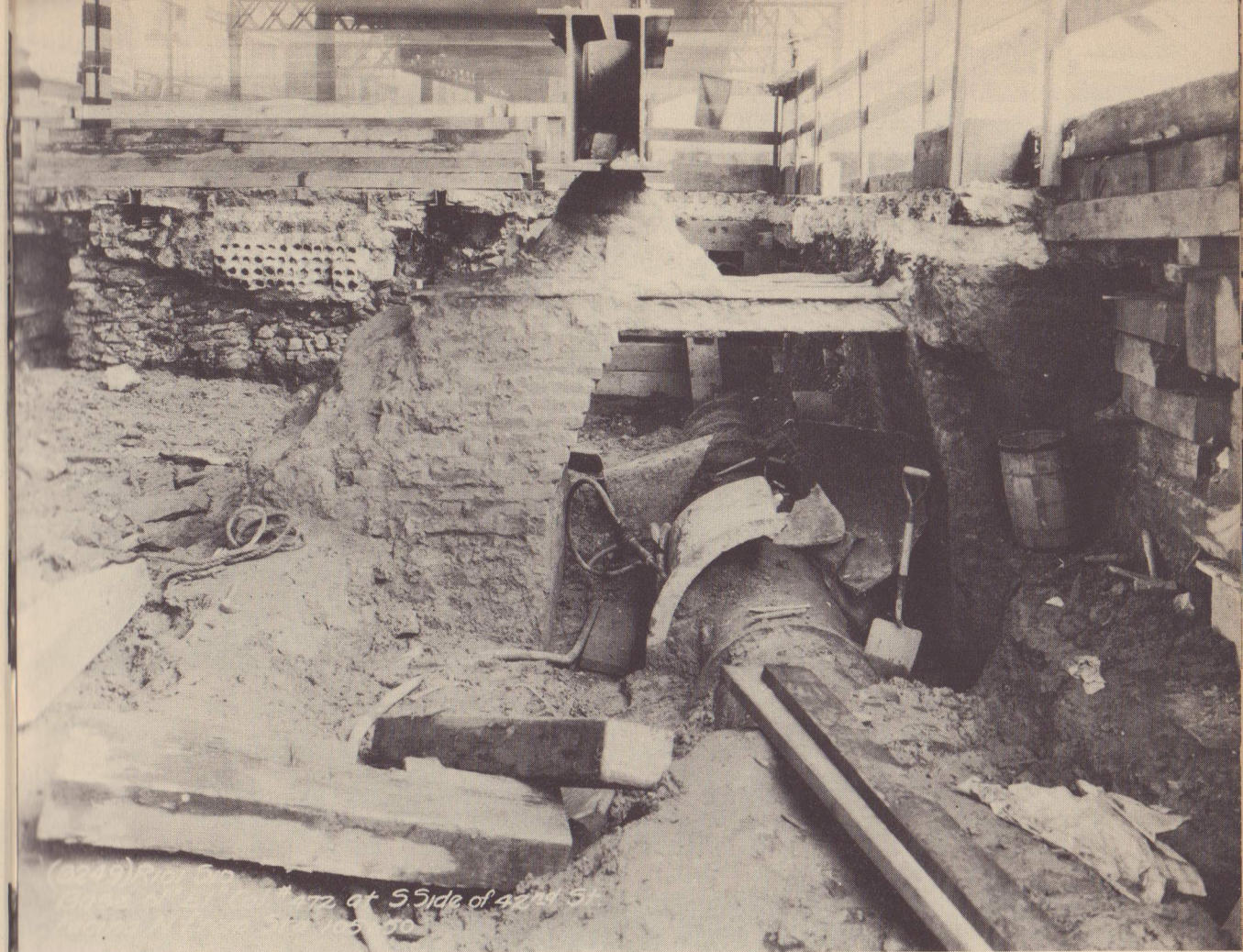
the whole mass of ducts has been concreted together. Such a block of concrete-enclosed cables is called a *duct-bank*. Sometimes these concrete conduits can be supported in place from below without interfering with excavation, but if they are in the way, all the concrete, and each tile duct, must be broken away and the cables themselves must be separately supported from the cross-beams.

Water mains, unless they are of enormous size, are usually suspended from the cross-beams. Sometimes great steel mains twenty feet in diameter are found, and even these must be preserved without moving if it is humanly possible. In such cases heavy concrete or steel piles may be driven under the main so that it is supported from the bottom of the subway far below rather than hung from the cross-beams overhead.

Sewers present perhaps the most difficult problem at this stage of the work. In New York, for instance, the sewers in nearly every case have to be replaced, because the old sewer mains were originally built out of brick or concrete and such structures never can be safely supported.

What they do is this: Instead of laying a new sewer outside the line of construction, which in most cases is impossible since the subway construction itself takes up all the space from building line to building line, the old concrete or brick sewer is broken into at the top.

Through this opening in the top of the sewer, right into the flow of the sewage, workmen lay lengths of new iron pipe which are just enough smaller than the original structure to permit their being laid inside it. These lengths of iron pipe are then fastened firmly together—so that now there is *a sewer within a sewer*! When all connections are made, the sewage is completely routed through the new iron pipe, and the old concrete or brick structure is cut away with bull



This picture has practically everything in it! In the foreground is a new sewer, with the pieces of the old sewer in which it was laid lying about. To the left, in the back, a big duct-bank, with all the pipes removed. And right in the middle of the picture, an elevated structure support. Note the extraordinary way it was built—with practically no support at all, underground! It seems to be resting on air. It's a wonder it didn't collapse long ago.

points and picks and shovels. The new iron pipe sewer can then be safely hung from the cross-beams.

With similar care all the other numerous kinds of pipes, cables and ducts are rerouted or suspended. In many cases, such as with electric, telephone and telegraph wires, and gas mains, the work is done under the direct supervision of the various companies which own them, and in occasional cases is even done by the companies themselves.

Never—except in the case of making temporary connections between gas bypasses and the houses along the street, or in case of unforeseen accidents—are the services of these subsurface structures to the citizens interrupted or stopped.

By the time that most of the subsurface structures have been taken care of, and often considerably before that time, excavation has gone deep enough for the contractor to begin laying the street and sidewalk *decking*. Usually decking operations begin when excavation to a depth of at least six feet extends for an area at least a block long.

DECKING

Decking is a temporary surface on a street, over which traffic can move regularly. The city does not permit prolonged interruption of traffic in any busy street, so an elaborate temporary road surface must be prepared.

Only in rare cases, when subways are excavated in relatively undeveloped sections of the town, can the decking be omitted. When this is the situation, you get the effect as pictured here.

The first step in decking is to sink wooden or steel piles, spaced ten to twenty feet apart, down into the ground by means of a great pile-



Excavation in open cut. No decking is needed. Above, a very wide street, with digging going on along half of it, without any temporary roadway. Below—Excavation across a vacant area.



driving machine. Piles are driven down to *subgrade*, which is the engineer's term for the depth beneath the street at which the bottom of the new subway structure will lie when it is finished. Driving piles to this depth is done only, of course, where the excavation is to be entirely in earth. If there is much solid rock which will have to be blasted out to finish the excavation, the piles are driven down to the top of this rock and pounded "until refusal," as the workmen call it—meaning, until they refuse to budge another half inch. This solid rock may be anywhere from a foot to ten or twenty feet below the surface.

Then, across these piles, from one side of the street to the other, heavy steel girders or enormous wooden beams are laid, so that they form bridges right across the whole excavation area. These *cross-beams*, by the way, are the same ones from which the subsurface structures are suspended for protection, as described a page or so back.

Most of us rarely see beams of wood of the size that is used for these cross-beams. Usually they are a foot square; and frequently the cross-beam is made up of two of these, securely bolted together, making a solid block of wood twelve by twenty-four inches in size. These great beams come from the first-growth pine forests of the South and the West, and are solid, aromatic-smelling, and free of faults.

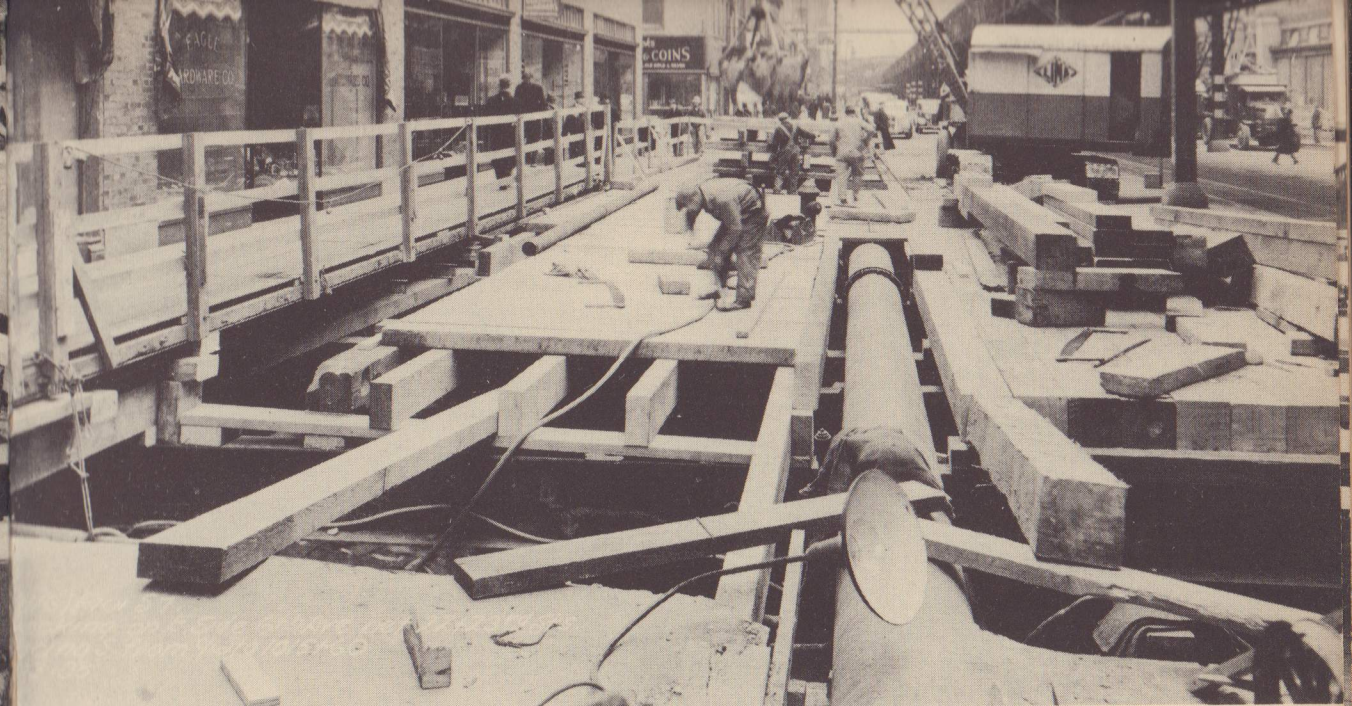
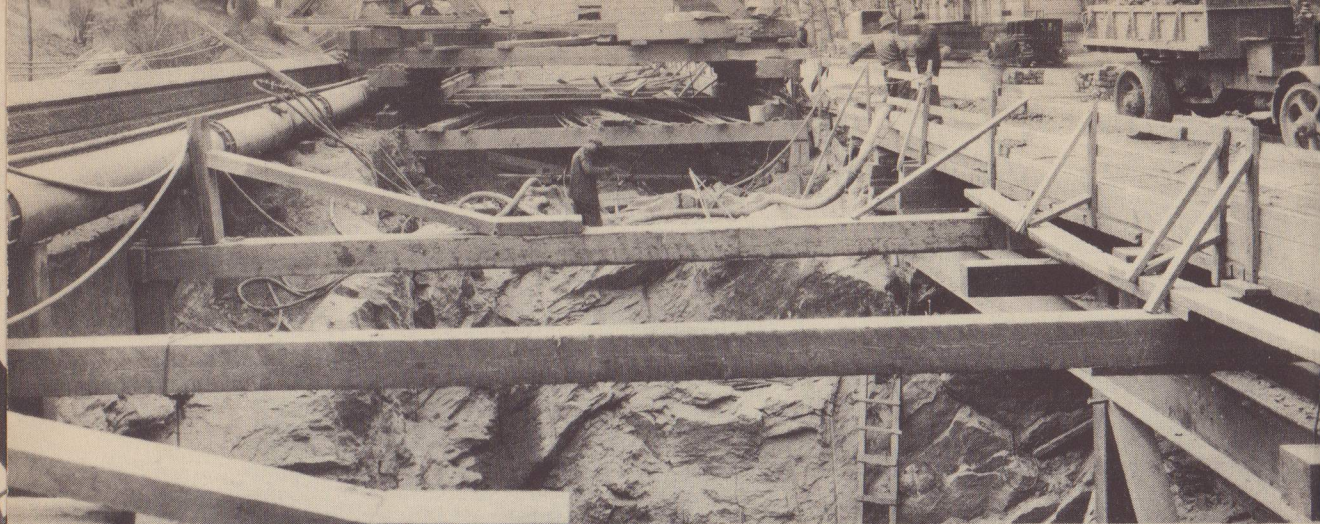
In most modern subway excavation, where enormous loads must be carried by the decking, heavy steel girders replace the wooden beams. But one still finds the pine cross-beams in areas where not so much weight must be figured on.

How much actual weight must the decking bear? In estimating that, the contractor must allow for the weight of all the street traffic—busses, trolley cars, trucks, passenger automobiles, and of course the enor-



5673) R101 S6.
Driving Piles at S.W. Cor 13th St & 5th Ave.
12:27:37

Driving the piles on which the decking will eventually rest.



Laying the decking. In the picture above, note the way sidewalk decking is laid: quite different from street decking, which is just huge 12" x 12" boards put down side by side. Below—A completed section of decking—everything as smooth and uncluttered up as if it were a permanent roadway.



Wooden cross-supports for decking are shown in the picture above. Not all of them are in place yet. Below—A glimpse of the steel cross-supports, seen through a section of decking which has been temporarily removed. The big white numbers show the exact location of each steel beam, in reference to the surveyors' stations.



(5840) Proj. Se.
Excavation at S.W. Cor. 6th Ave. & 14th St.
Facing N. 5/7/38

mously heavy derricks and power shovels which he himself uses in continuing excavation underneath the decking. But, in addition, the decking must also carry the weight of the subsurface structures suspended from the cross-beams; and some of these structures are enormously heavy. Water mains filled with water often weigh as much as *a ton a foot*, sometimes even more. Sewers are even heavier.

Not only must the contractor consider the actual weight the decking must carry, but he must allow perhaps as much as 100 per cent more for possible contingencies. Thus it can be seen that the decking of a subway under construction is in itself a big-time job for the builder!

After the piles and the cross-beams are in place, the actual decking is laid on top of the cross-beams. This decking is always of wood, and in most cases consists of six-by-twelve-inch pieces of pine, running in length to exactly the distance between the centers of the cross-beams: that is, ten or twenty feet long. The beams are nailed or bolted to the cross-beams, and then at last traffic can proceed as usual over the new, strong wooden decking, while the actual building of the subway goes on underneath.

UNDERPINNING

In the meantime, while digging and decking operations are going on, other engineers and workmen on the contractor's staff are *underpinning* the buildings along the line of excavation.

The purpose of underpinning is to strengthen and protect the foundations of the buildings so that they will not slip into the excavation, bringing the rest of the structures down after them. You can define underpinning quite simply as *extending the foundations*



Here is a place (above) where the sidewalk decking is only a narrow bridge. Excavation work is going on where the rest of the sidewalk should be. The strange looking little outhouse in the picture below is actually the entrance to a flight of steps going down to the excavation itself. This is the way the workmen get down to their jobs.



of a building down far enough so that they will rest on solid rock, and be protected while excavation is going on alongside of them.

In most cities with old buildings in large numbers, underpinning is itself a larger and more difficult job than anything we have described before. Take, for instance, New York, where most houses, including office buildings, apartments and lofts ten stories high or higher, were built twenty-five or more years ago. In those days foundation work was not as well understood as it is now. The builders would dig a hole for a cellar, and just build the building on top of it, even though the ground beneath was all sand or broken rock or earth. Engineers find that the foundations of such buildings as these sometimes go down less than ten feet under the surface of the earth! These buildings are truly "built on sand."

And every one of them which is along the line of a subway job has to have its foundations reinforced—carried down to rock, and securely fastened there: a process which is done by sinking piles underneath the existing foundation and letting the piles bear the weight of the building.

A modern skyscraper, of course, is a different business. The builder of Radio City, or some other such monster skyscraper, drives foundation piles clear down to solid rock before building; and thus his structure is "built on rock," even though that rock may be sixty feet or more below the basement of his building.

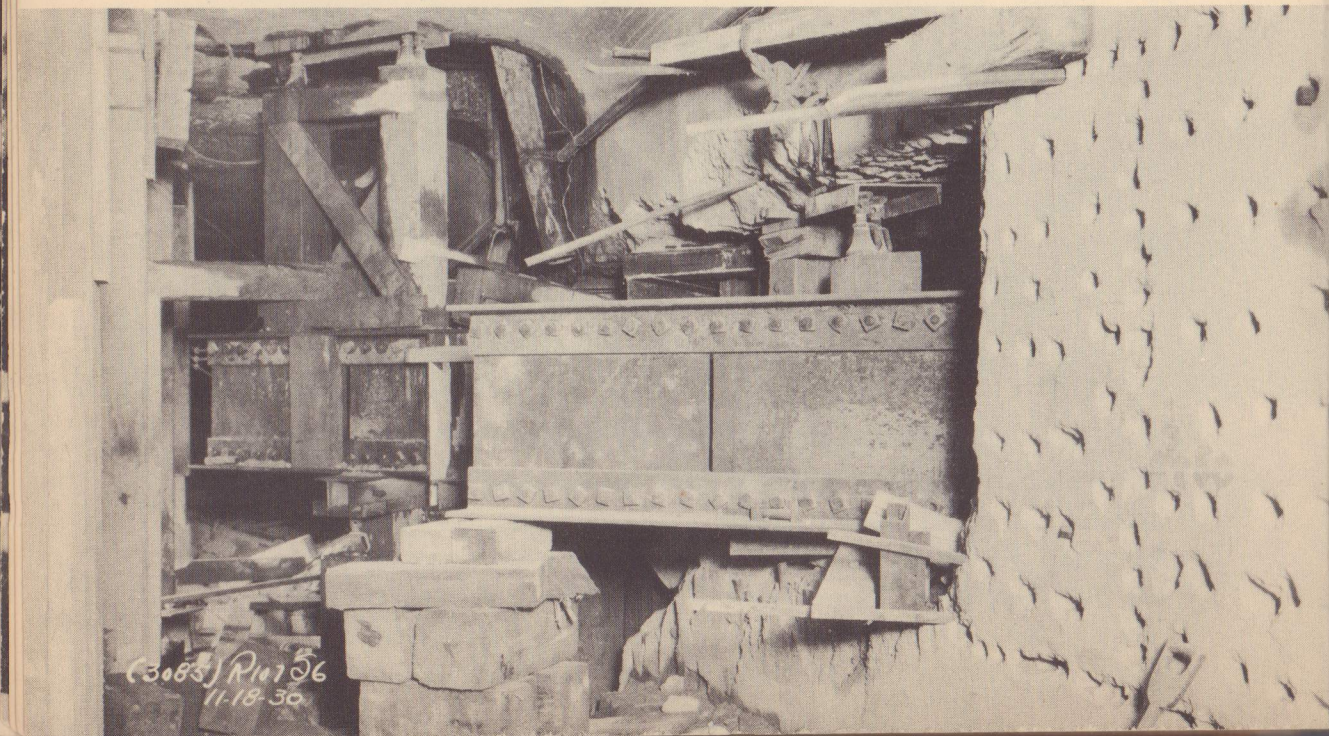
One of the most interesting problems involved in underpinning is that of protecting the basement rooms of buildings, many of which extend out under the sidewalk. One can usually tell where there is such a basement room by the round glass blocks embedded in the pavement, which allow a little light to enter the rooms underneath.



A sidewalk vault has been taken over by the city, so that underpinning of the foundation of the building itself can be done. Note the "sidewalk lights" in the upper right-hand corner (the glass blocks which let light into the vault). To the right is a wooden partition which protects the rest of the basement from the excavation. The great steel beam on which the pillar of the building foundation rests is a type of needle-beam, used when foundations are in the form of pillars, and not continuous walls.



The two types of underpinning. Above, a "grid-beam," supporting a small frame building. The foundation has been cut away, and the building rests on the steel beam. The "needle beam" below is holding up a section of extremely heavy wall, so heavy indeed that there are two needle beams in the same hole.



Frequently these basement rooms must be destroyed by the builders; and in that case the city makes special arrangements with the property owners. But if the subway structure is to run only from curb line to curb line (from the outer margins of each sidewalk, that is) instead of from building line to building line, the sub-sidewalk rooms (or *vaults*, as they are called) must be carefully preserved. And due to the age of the foundations, and the lack of care taken originally to make them very strong, the walls of these rooms must frequently be completely rebuilt by the contractor, giving the property owner a nice new vault!

The most important problem is, of course, the underpinning of the buildings themselves, when excavation is to go from building line to building line. The two methods of underpinning most in use are called *needling* and *gridding*.

Needling is used with many types of basement walls. The workmen dig small pits, or tunnels, under the foundation, spaced every three or four feet, and heavy short steel girders are pushed horizontally through these holes under the foundation so that they rest directly against the base of the wall. These girders are called *needle beams*.

Then steel or wooden piles are driven under each end of every needle beam, down as deep as the foundation must be carried to be safe during the excavation. Next, by means of *hydraulic jacks* or *screw jacks*, two tools much used in underpinning, the weight of the foundation wall is transferred to the needle beams and their piles, so that, if necessary, the wall can even be dug *under*, and in any case will be kept safe from collapse.

The gridding method is used only when the foundation walls are very thick, for then it is perfectly safe to dig a trench along and under



Here is a photo of a series of pillars, which have been underpinned by means of the direct method mentioned in the text. Piles have been driven directly under each pillar, and the whole thing made solid by filling the piles with concrete. Below, holding an old building together with string! It started to crack as excavation got under way, and the contractor strapped it with steel rope and propped it with a strong support.



Sometimes underpinnings fail. Above, the front of a grocery store has fallen into the excavation. Not a serious tragedy, however, like that shown in the picture at the left, where a whole building simply disappeared into the cut, not one brick being left standing. Such catastrophes happen very rarely indeed.

a certain proportion of the wall. When these trenches are dug—one on the inside and one on the outside of the wall—very heavy *grid beams* are slid in the trenches along the whole length of the foundation. A grid beam is just a very heavy and strongly made steel girder, which will carry the weight of the building above. After the grid beam is in place, supporting piles are driven at each end of each grid beam, and at intervals in between; and the building load transferred to this system of beams and piles by means of jacks as mentioned above. The foundation now rests on a long, continuous pair of girders, supported by deeply sunk piles.

These are only two of the simplest methods of underpinning. A third, and quite new way is to drive concrete-filled steel piles *directly under* the foundation, instead of under the needle beams or the grid beams. In this case, of course, many short sections of piling must be hammered down, one on top of another, since there is no room for a great twenty or thirty foot pile to be driven right under the wall.

Sometimes special cases arise when subway excavation must be done wholly under a building, without disturbing the building at all. The methods of work in such a case are extremely complicated and involve the use of methods which one could understand only if one had been to engineering school. In the same way, underpinning bridge supports and elevated railway structure supports is much too complicated for description in a short book like this.

Now that the decking has been laid, the subsurface structures cared for, and the buildings underpinned, we shall proceed to the most dramatic parts of excavation work.

CHAPTER FIVE

MORE ON EXCAVATION

AT THIS point we are confronted with several novel problems, now that we are ready to continue excavation below the seven-foot depth which was dug before the decking was laid.

In the first place, very few areas in the world are completely clear of rock. In New York the borough of Brooklyn is the only place which has very little rock in it. It is mostly sand and clay, and there digging is mostly a matter of shoveling out with power shovels down to the required depths, as will be described later.

On the other hand, Manhattan and Bronx are founded mostly on rock, and there a typical piece of subway construction usually involves *both* earth and rock excavation, often in the same cross-section area of digging. The earth layer may be ten or fifteen feet thick, with solid rock lying beneath. And since the subway must be excavated to a minimum depth of twenty-five feet, the digging will have to be done both through earth and through rock.

This means blasting as well as digging and carting away.

BLASTING

Dangerous though it is, blasting is actually quite a simple process.



Closeup of a drilling machine. Note how long the drilling arm is. A man has to stand above the surface into which he is drilling, in order to be able to hold the machine upright.

After the earth layer, if any, has been dug away, crews of men descend into the excavation, each one with an air-power drill. This time they have special rock-boring bits in the machines—they call them *jack-bits*—which have cutting edges in the shape of a cross, with a hole down through the bit where the center of the cross is. As the drills bite into the rock, the rock dust is forced out through these holes by means of a special jet of compressed air. The jack-bits themselves are over an inch and a half in diameter, and bore a hole in the rock big enough so that a stick of dynamite can be inserted in it.

After the holes are bored in the solid rock face, the dynamite men come along, put a stick of dynamite into each hole, and fix an explosive cap to it. They connect all the pieces of dynamite in their holes together by a system of wires, and then run another wire some distance away to a blasting box, where a man waits to set off the blast by sending an electrical current through the wires when everything is ready.

Before the blast, a near-by crane lifts up an extremely heavy steel-rope blanket such as can be seen in the picture on page 80, and lays it over the blasting area, to protect workmen and bystanders from flying pieces of rock.

Finally the dynamite is set off with a great roar and clatter of enormous boulders falling. The blasting mat tosses about as if it were alive for a moment, and then everything settles down into a cloud of dust.

The first blasting done on any job is the sinking of a *shaft* from the rock surface clear down to subgrade. When that is done, the men begin blasting horizontally under the street, cutting their way into the *heading*—the heading being the technical name for that part of the excavation on which they are working at the present moment.



The drillers in the picture above are working with short drilling arms, and are putting down dynamite holes right up against the heading. The next blast may knock out several feet of the rock. Below, a blast has been set off, and the workmen are clearing up after it, pushing pieces of broken rock down to the bottom.



Two types of drilling holes. The heading above is completely riddled with holes, so that the whole area will be blasted loose. The row of holes in the picture below is just enough to break up the particular rock the holes are in. (Bottom photo, courtesy of Spencer, White and Prentis.)



(1556) Rio 510
6-1 Ave Cut bet 45+46+51
Facing 5' from 1/2 Sta 10+35
Shoring Rock Heading 1/2



The blasting mat is in place, and the workers are scrambling out of the excavation before the blast is set off. Unfortunately, you cannot take a picture of a dynamite blast!

Sometimes, if the subway is being dug deeper than twenty-five feet below street surface, the men find it necessary to do the work in *benches*. In this case the shaft is blasted only to the depth of the first bench—ten to twenty feet, perhaps—and blasting is then carried on horizontally from there. Then later the crews return and complete the shaft to the bottom, and remove the second bench of rock. A bench is really just a section of rock small enough to allow its being blasted out without danger of collapsing rock, such as one might run up against if the section were exceptionally high. In unusually deep blasting work, there may be three or even four such benches.

After the rock has been drilled and dynamited, the debris has to be removed from the scene of excavation, of course. So crews of workmen climb back into the cut and begin piling pieces of rock into conveyors, or buckets, of which there are several types. When a conveyor is filled, an overhead crane up on street level lets down its hook, and the men fasten it to the conveyor and it is hauled above and dumped into a waiting truck. When all is cleared away, the drillers start again and prepare another blast.

You may wonder how a crane can be conveniently located just where the actual excavation is going on, and how it can lift the excavated material out through the solid decking. Well, that was taken care of when the decking was laid.

For along the sides of the street, or even in the sidewalk decking if excavation is being done that far in toward the building line, the top layer of decking boards, which was laid across the cross-beams, was firmly fastened together in *hatchways* measuring ten feet square or more. The crane comes along and lifts a hatchway clear of its place in the street surface, putting it aside; and through the hole left, the

crane can pull up the buckets filled with dirt and rock which the men are filling down below.

The two types of excavating buckets most in use have curious names—the *tip-over* and the *battleship muck bucket*. The tip-over does just what its name says it does—it tips over and pours the rock and earth into the waiting truck. But the battleship muck bucket opens down the middle, like the clamshell type of shovel excavator, and empties the material out through its bottom.

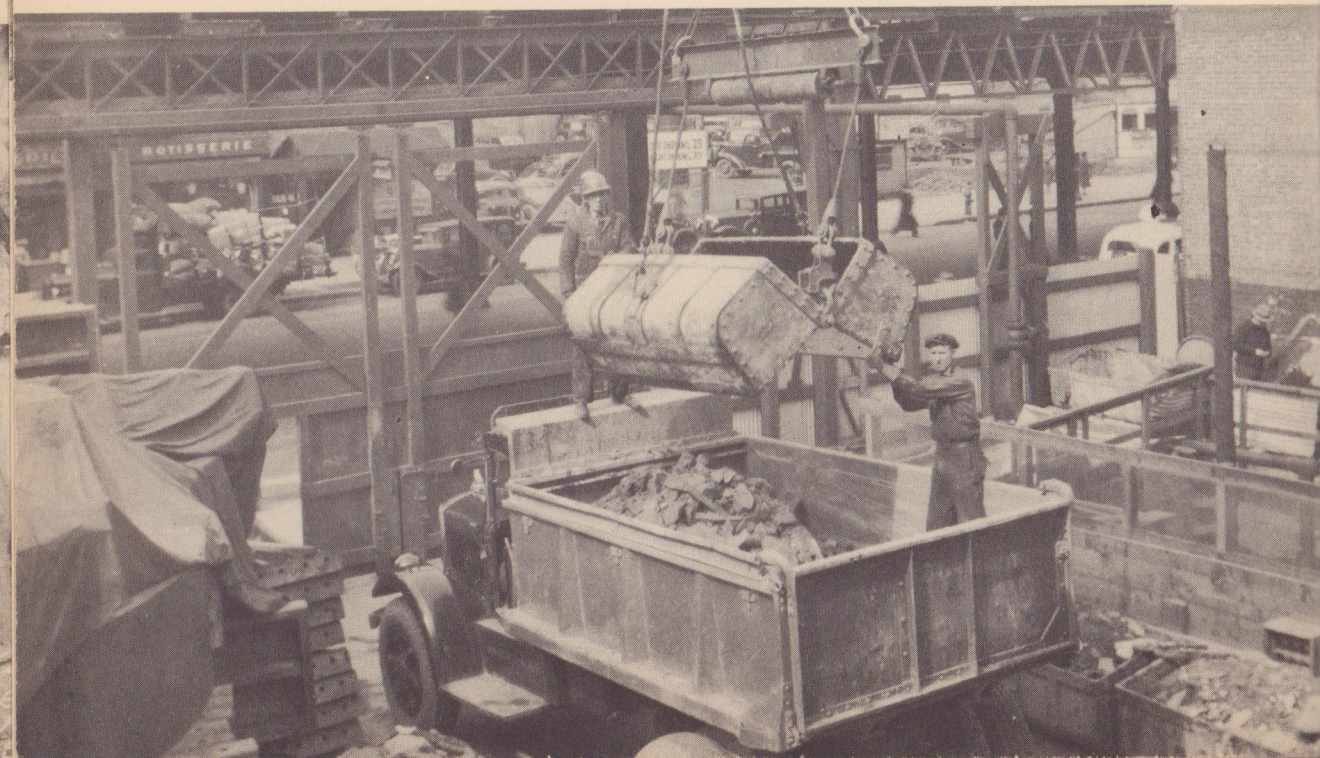
EARTH EXCAVATION

In straight dirt digging, either the workmen below shovel the earth and the small rocks and other debris into tip-overs or muck buckets, or else a specially designed tiny power shovel, small enough to squeeze into a space no more than eight or ten feet high, scoops up the material and dumps it into the waiting buckets. In both cases the crane overhead then lifts the overflowing buckets to the street and empties them into waiting trucks.

Sometimes, when the dirt excavation to be done is composed of loose earth without too many boulders in it, the crane itself, far up on the sidewalk, does all the excavating without the aid of a power shovel or a large crew of excavators under ground. A regular clamshell power digger, which is a combination of a crane and a "steam" shovel, is then substituted for the simple crane. This machine is called a clam-shell because of the obvious resemblance of its excavating part to the shell of a clam.



Two types of excavation buckets. Above—A power shovel is piling rock into a "tip-over," which an overhead crane will pull up when full. Note the chain around the big boulder. It will be hoisted by the chain. In the bottom picture, a type of battleship muck bucket is dumping its load into a waiting truck. (Bottom photo, courtesy of Spencer, White and Prentis.)



Here the operator of the clamshell is really the only excavator on the job, except for a man down below who operates what is known as a *bull-dozer*—a machine very much like a snowplow fastened to the nose of a small tractor. The operator of this bull-dozer goes back and forth along the floor of the excavation, pushing the dirt up to the place where the clamshell is picking up its tremendous mouthfuls of earth. Actually, the bull-dozer slowly lowers the floor of the excavation down to final subgrade—by pushing it out from underneath itself!

There is a third man, a guide, in the clamshell-bull-dozer crew. He stands at the point where the clamshell is working, and directs the operator "upstairs" as to where he should drop the bucket next. Thus a crew of three men now do the work which dozens of laborers used to do by hand.

A variation of the surface crane method, used when cut-and-cover excavation must go down very deep, or when it is inconvenient to have movable cranes going from place to place along the street as digging progresses, is called the *shaft-hopper* method. The shaft-hopper is also occasionally used in tunneling, which will be described in the next chapter.

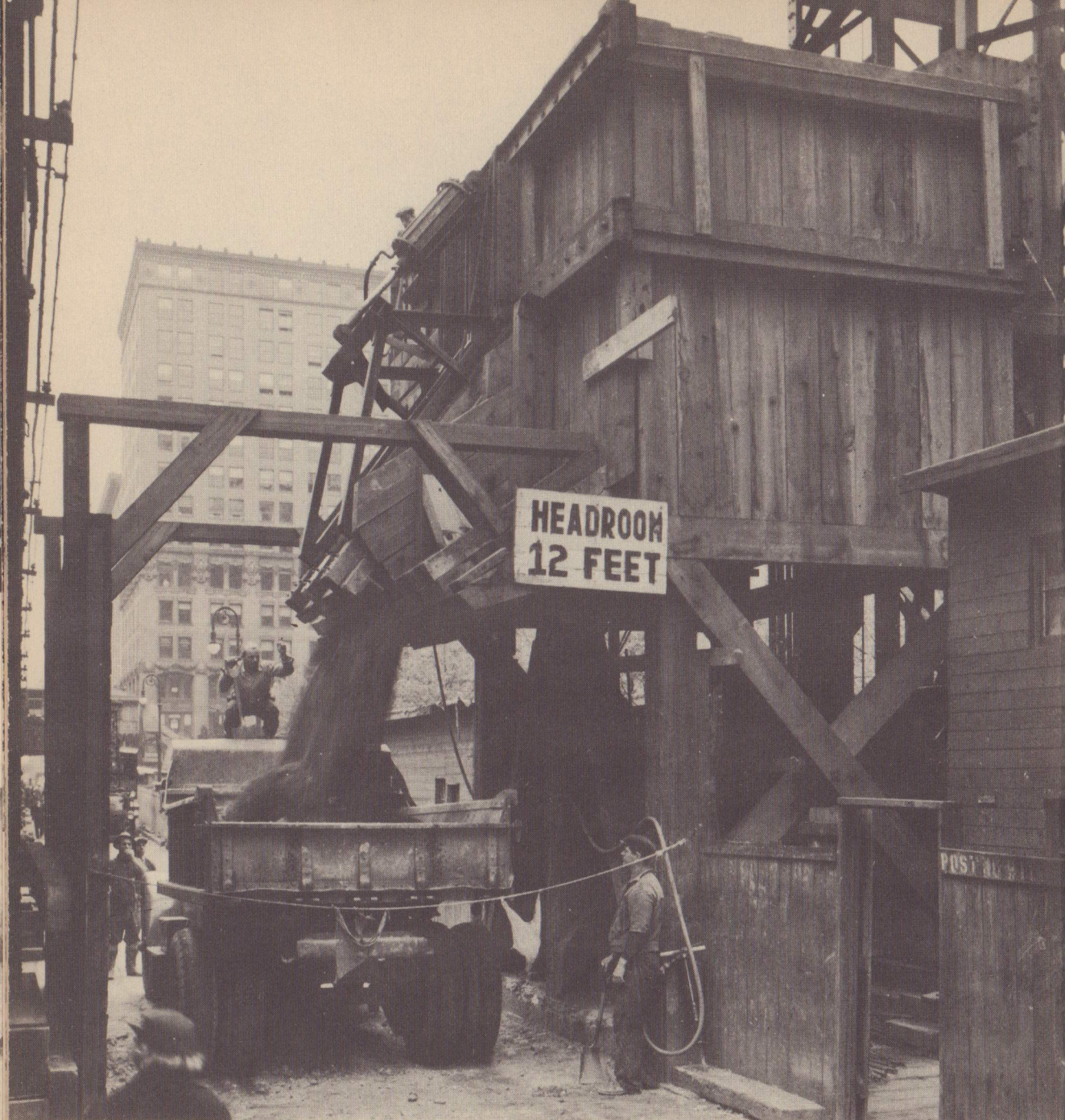
A shaft-hopper is a semi-permanent structure, containing strong hoisting machinery with which buckets filled with material may be pulled up from the floor of the excavation and tipped into a hopper, which then feeds the earth into waiting trucks.

For such an arrangement, types of *industrial track* (see page 106) down in the excavation are required; this track carries cars which bring the material from the heading where digging is proceeding to the bottom of the shaft-hopper.

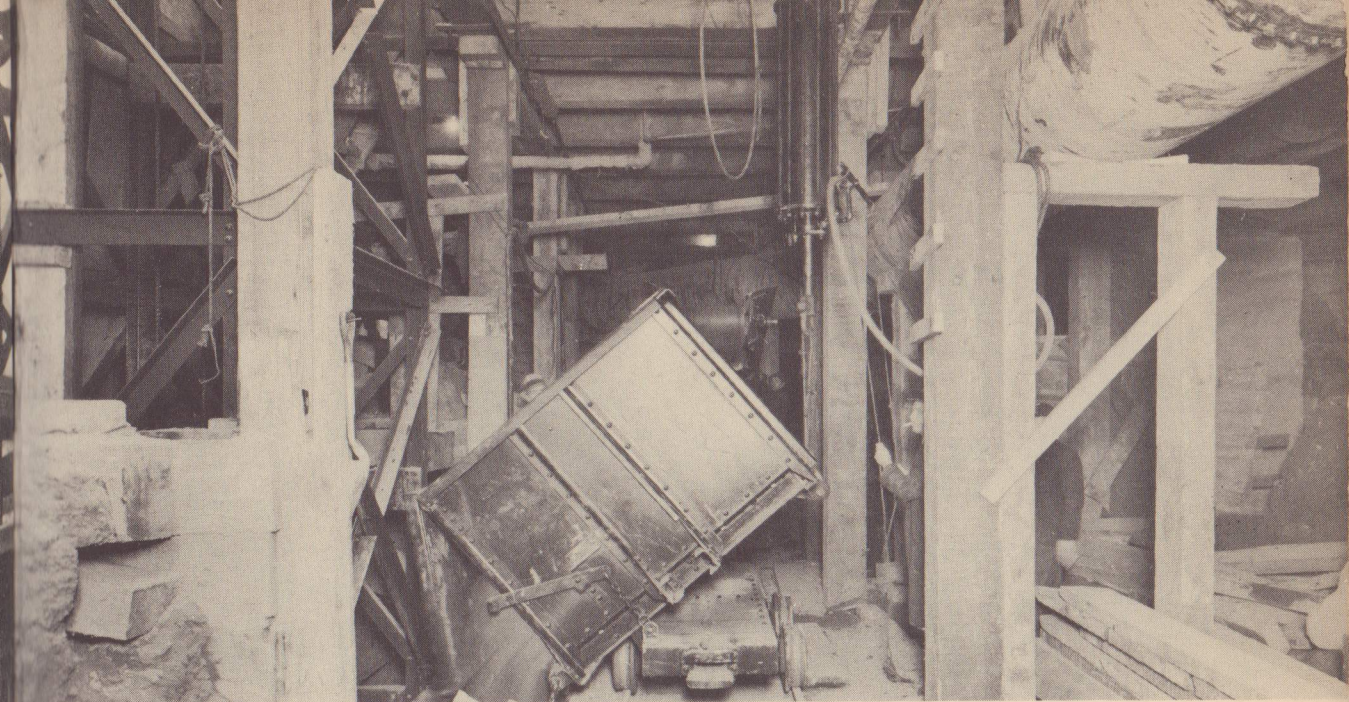


The bulldozer above is pushing the loose earth in toward the place where the power clamshell digger up on the sidewalk (see the picture below) can grab a mouthful of it in its jaws and lift it up.

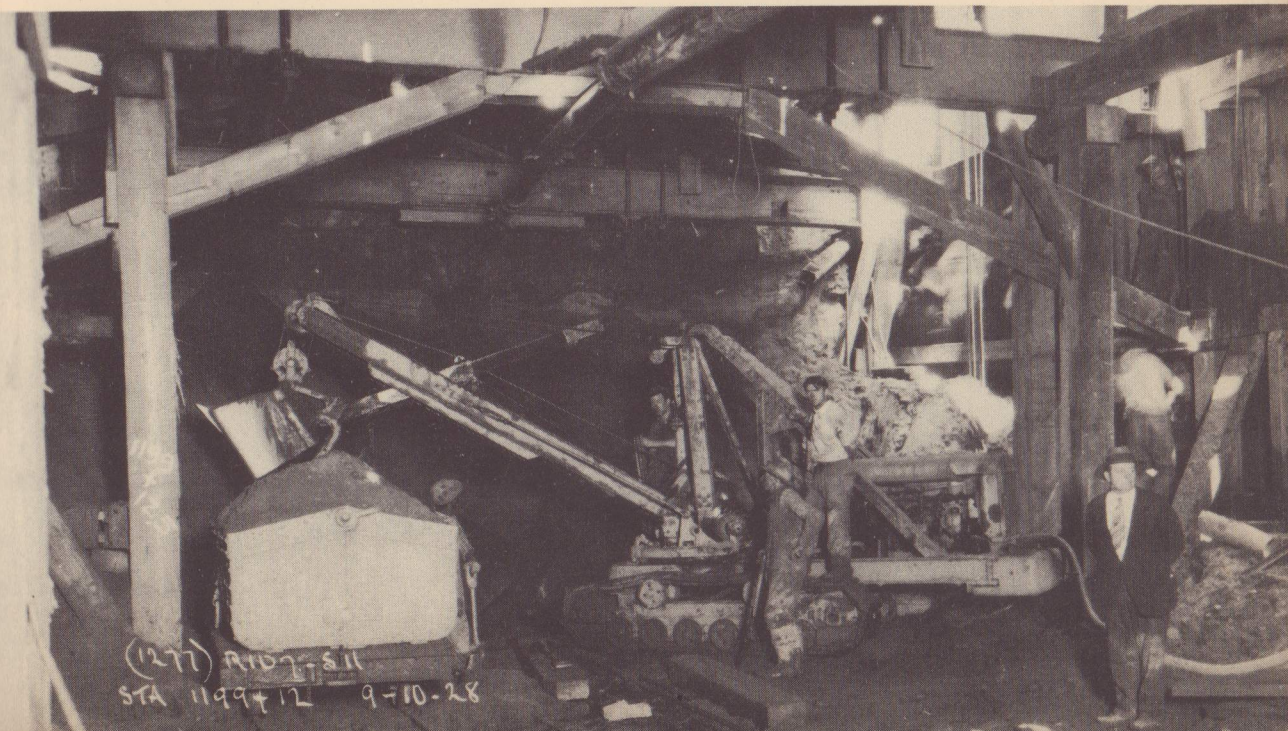




A shaft-hopper in action, pouring dirt into a truck. The man whose head you see away up on the top of the hopper is the one who will shut the thing off as soon as the truck is full, and the fellow crouched on the front of the truck gives the signal.



Another type of tip-over bucket. This one runs on industrial track, and is used to collect and dump muck into the shaft hopper. An elevator in the hopper hoists the material to the top, from which it is released into waiting trucks, as in the previous picture. Below—Still another type of bucket, on an industrial track. The car will be pulled to the shaft-hopper, and the bucket itself lifted to the hopper and dumped.



RAMP EXCAVATION

Until quite recently these were the only methods of excavation in cut-and-cover work. But of recent years, with the development of very powerful motor trucks, a new way of doing the job has been perfected.

First, an area of the subway is dug out clear down to subgrade (or to the first bench, if the work is to be done in benches), leaving behind, however, a graded section of earth and rock which forms a *ramp* leading up from the depths of the subway cut. In this method, every bit of excavation, except for that part done before the decking is laid, is done under ground, and no shovels or cranes are in the way on the street surface.

Sturdy little power shovels, the same as are sometimes used in overhead crane digging as described a few pages back, are run down these ramps, and immediately they set to work digging. Following the power shovel down the ramp come a series of those extraordinarily powerful trucks which have made this method of work possible. The shovel digs up a bucket full of earth—from a quarter of a cubic yard up to one whole cubic yard in content—and then swings around on its chassis to where the truck waits, and dumps the earth into the truck body. When full, the trucks climb back up the steep ramp roaring and struggling with their heavy loads, and rush off to the distant spot where the excavated material is being dumped.

This ramp method can be used when there is blasting, too. In that case the power shovel picks up all the pieces of rock which are small enough to fit into the shovel part, while the larger pieces are either broken into smaller pieces with power drills, or else they are lifted



Another type of shaft (above) in which a "stationary crane" hoists material in buckets and dumps them into trucks. The queer contraption below is known as a "telpher"; it is a kind of shaft which moves along with the excavation as it proceeds! It is on log rollers, you will note. The telpher method is very rarely used, being cumbersome and awkward.



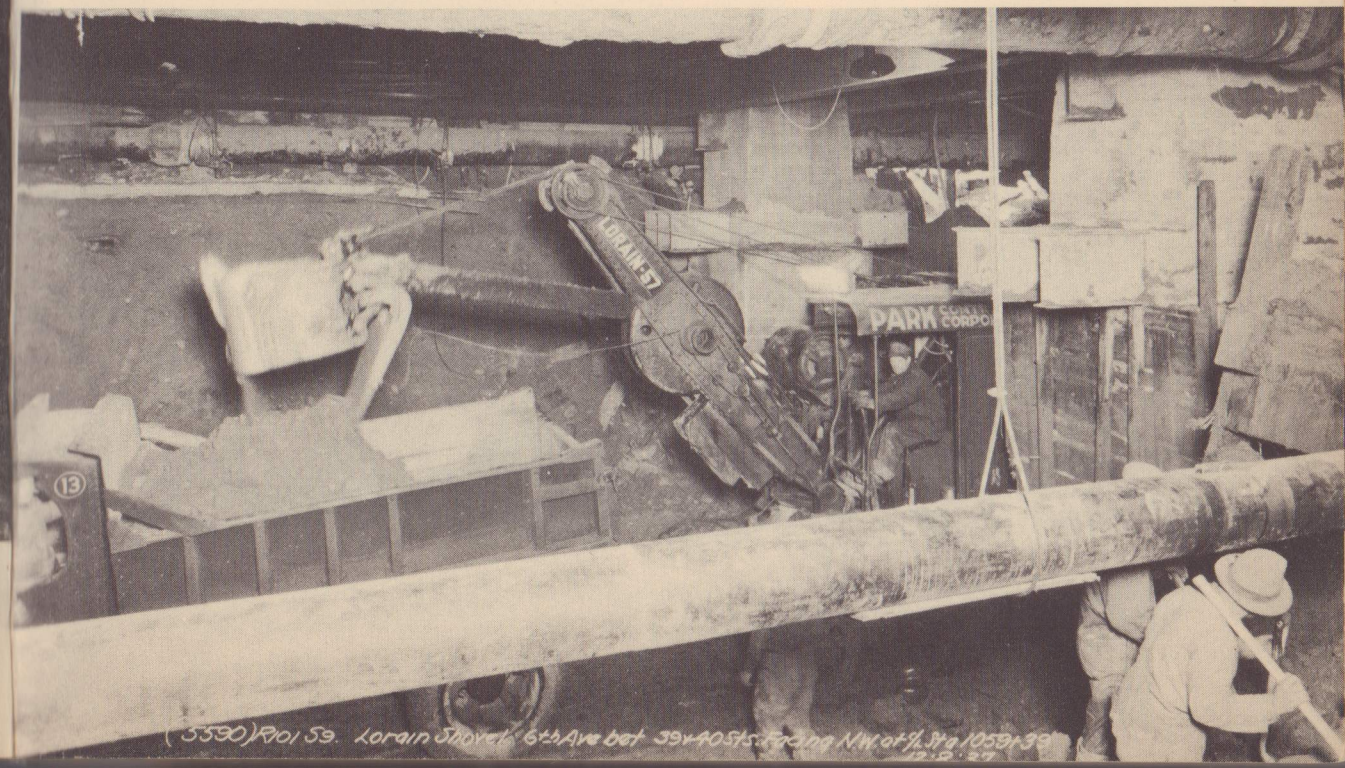


(5589) R101-59
Hatchway, 6th Ave bet 361-37 St
Facing S at 4th St 10521-95
12-8-37

Coming down a ramp. The truck must come down in low gear, very slowly, for the grade is extremely steep.



The truck is getting its load of dirt (above). Here excavation is done directly by power shovel, which digs into the heading, swings around with its beak full of earth, and dumps it into the truck. Below—A loaded truck just emerging from the ramp.



(5590) R101-59. Lorain Shovel, 6th Ave bet 39-40 Sts. Facing N at 4th St 10521-95
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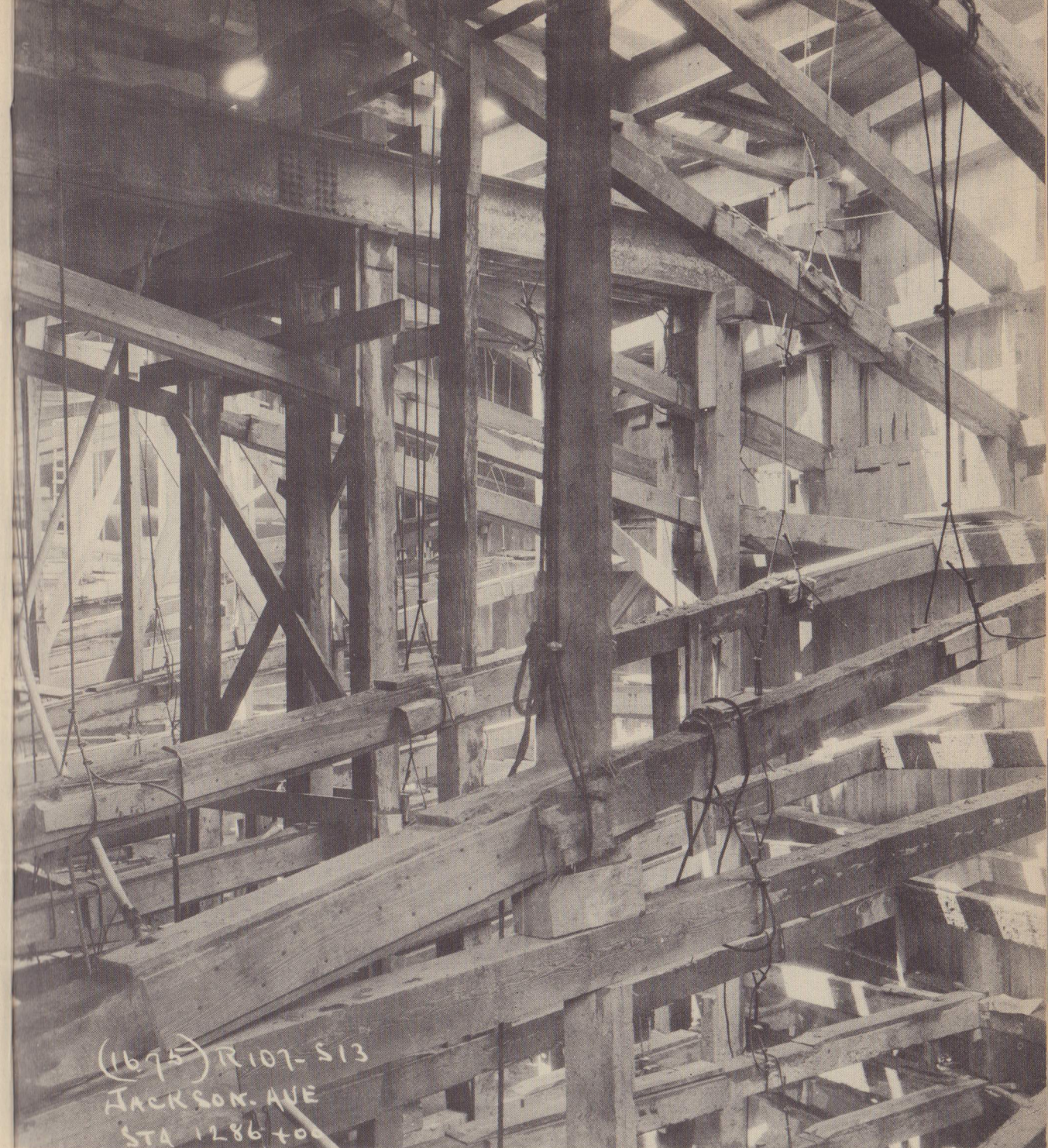
into the trucks by means of chains slung around them and fastened to the arm of the power shovel. The shovel then hoists the huge boulders into the trucks.

The fact that machinery has replaced the hand method of excavation has not meant that workmen cannot find jobs on subway excavation work. Plenty of workers find things to do in the building of a subway—drilling, blasting, “mucking” (which means digging earth and rock in such places as shovels and cranes cannot reach). In addition to the excavators many other men are employed for more specialized tasks, such as timbering and concreting, which must be done while excavation is in progress.

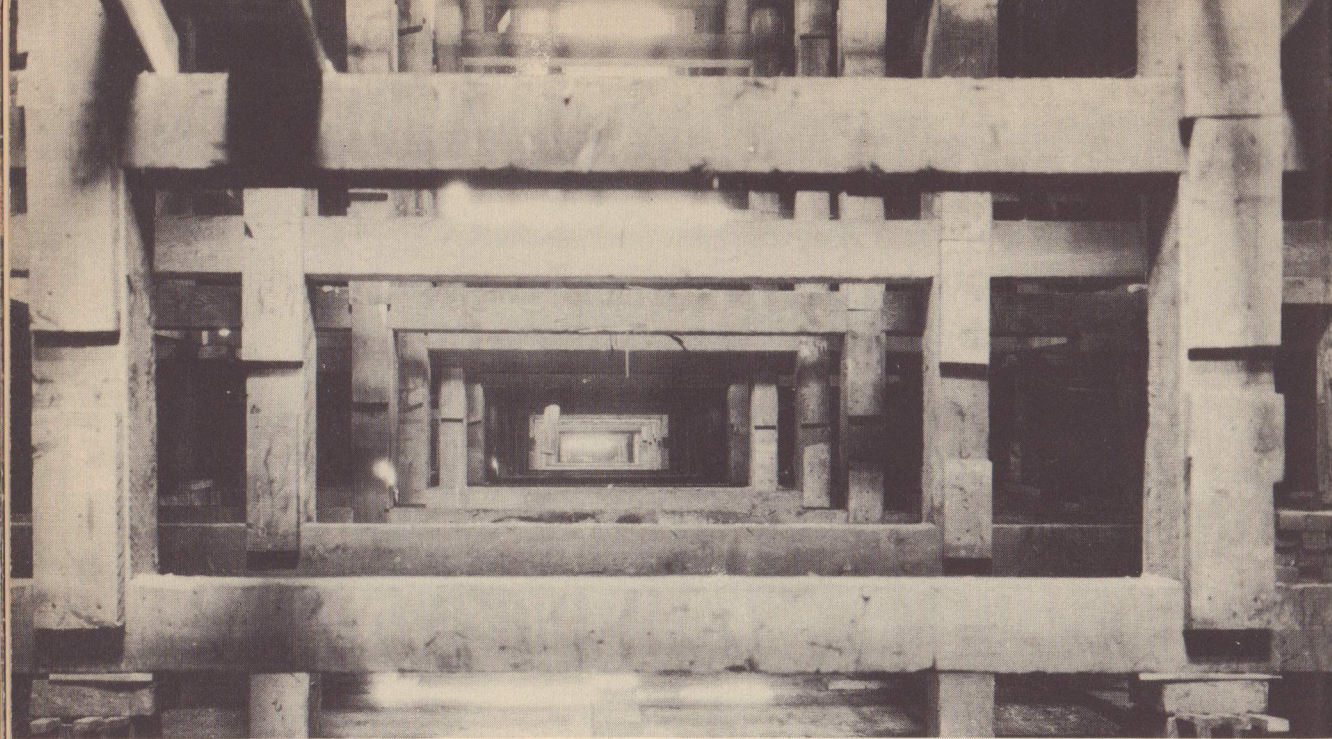
For the building of a subway is not, as you must realize by this time, just a matter of digging a long hole in the ground and laying tracks in it! Even while raw excavation is going on, a great many other tasks must be accomplished.

SHORING

It is impossible, for instance, to dig down to subgrade—anywhere from twenty-five to seventy-five feet below the street surface—and not support the side walls of the excavation in some way. So, as the work goes down deeper, building crews come along and put in great masses of temporary supports, the various types of which are called *shoring*, *bracing* and *timbering*, all of which serve to keep these side walls from collapsing. This is done even in rock excavation, for you never can tell when there might be a serious rock slide which would bring the decking down with it, or even one of the adjoining buildings, if it had not been strongly enough underpinned.



Shoring at its worst. One wonders how anyone could do any work in all that mess of wood. However, the permanent steel will eventually be put into place, and all the lumber will be removed.



Another view of wood shoring, above. But notice, below, how much clearer the excavation is when steel is used. Sometimes, of course, even more steel has to be put in, but it never is as confused as it is with wood. (Bottom photo, courtesy of Spencer, White and Prentis.)



Many subway contractors use sheet-steel piling as their wall support, and brace this piling with heavy steel cross-girders; others use wood-sheet piling firmly braced by heavier wooden beams or by structural steel. The use of steel girders is perhaps the best, since it means that there will be less obstruction in the subway cut. Steel is stronger than wood, and less of it is needed for shoring and bracing.

Moreover, all this time special care has been taken that the subsurface structures were strongly supported, and that the decking itself was firm. Many contractors make sure of this by placing a great maze of temporary timbering in the excavation. This timbering is just as much in the way as is that used to support the side walls, and for that reason many modern contractors who use steel for side-wall support also adapt the same girders scientifically into a system which will support the decking as well.

IN A SUBWAY CUT

Now what is it like, deep in a subway cut, once the excavation crews have dug down through dirt and rock to subgrade, the decking has been put in place, and the side-wall and decking supports are complete?

Have you ever been in a cave? If not, probably you have seen pictures of the inside of Mammoth Cave, showing the deep caverns, weirdly lighted with infrequent little electric light bulbs—a gloomy, cold and awe-inspiring sight.

In many ways the effect inside a subway cut is really much like that. There are no stalactites or stalagmites, of course, though the decking supports remind you of them. The decking overhead keeps out most of the light, so that strings of electric light bulbs hanging down from

loops of wires hung near the top of the excavation give the only illumination. It is surprisingly cold down there, even on a summer's day. Engineers have figured that it takes seven full years for the temperature in a new subway to reach the level of that up on the street!

In this dank, dimly lit, long underground passageway work the crews of men, like moles boring through a field. They have many difficulties to contend with, the chief of which is probably *water*.

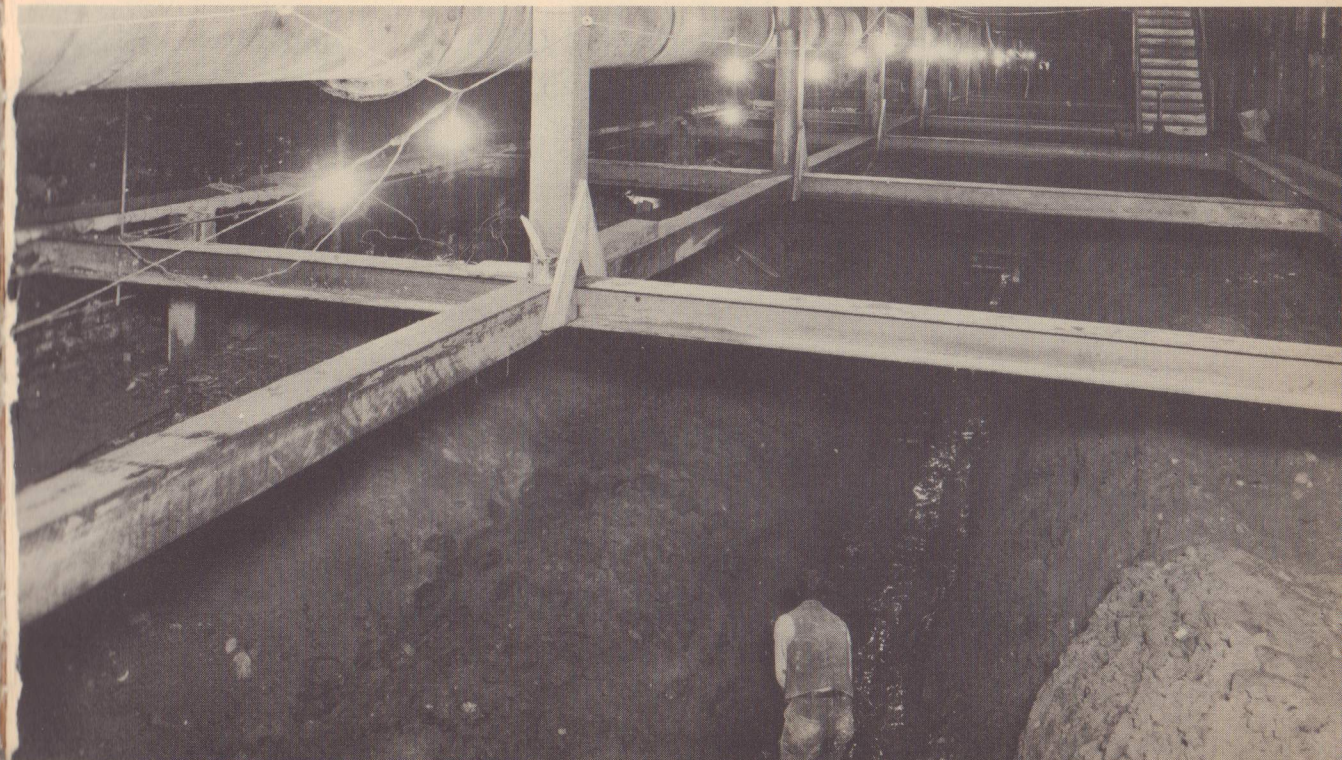
New York is a pretty level city, lying right at ocean level. So digging does not go down very far before water begins to seep into the cut through the sides. Usually it does not flow in in great quantity, but if, as sometimes happens, the men dig into some underground brook or buried spring, there is likely to be real trouble. Otherwise, the water just slowly collects on the floor of the subway, making it a great sea of mud through which the workers slosh in rubber boots or heavy waterproofed shoes.

To make this less annoying, and to dry out the bottom of the excavation so that the concrete base of the subway structure can be laid, temporary drainage ditches are dug along the bottom; and these drain most of the water off into temporary *sumps*. A sump is a large, specially prepared hole in the ground where water can collect until there is enough to be pumped out with big power pumps. These pumps—run either by air pressure or by electricity if they are under ground, or by gasoline if they are on the surface—lift the water out of the sump and into a temporary opening in the street sewer.

Even with this drainage system a subway cut is always damp, cold and dreary. Imagine the effect of steam shovels, roaring trucks, riveters fastening in the temporary steel shoring, and workers shouting directions, altogether setting up such a clatter that at times you can



Water in a subway cut. Floods like that do not often occur; but to keep such things from happening at all, the drainage ditch (below) is usually dug. Then the water runs off, and people can work with less discomfort.

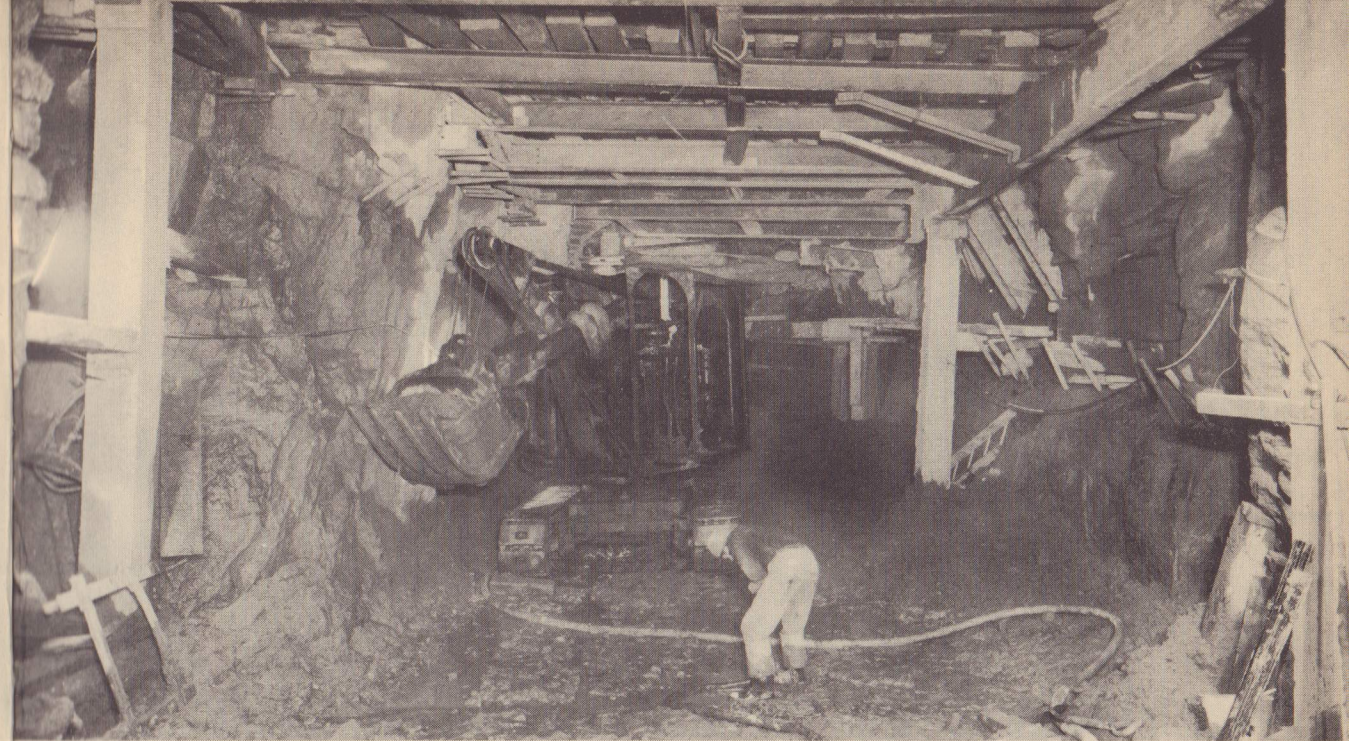


hardly hear yourself think in this gloomy, echoing cavern! And when you add up all this noise, the darkness, and the damp coldness, you have something of an idea of what an average subway excavation job in dirt is like.

When it comes to clean rock excavation, the situation is better in some ways, but worse in others. The worst thing to cope with in rock excavation is noise—noise—noise. You simply cannot imagine the racket caused under ground by a half a dozen powerful rock drills biting into the rock heading all at the same time. It is terrific! Men get used to it, we imagine, but even then it must be pretty hard on their ears.

Aside from noise, the most unpleasant problem to be dealt with in rock work is dust. You cannot drill holes in rock without scattering a tremendous amount of rock dust from the point of drilling. It is this choking dust which lodges in workmen's lungs and causes the dread industrial disease known as silicosis.

Certain precautions are taken, of course. In the first place, most rock drills have a water connection. You will recall the description of a rock drill we gave several pages back—a cutting edge in the shape of a cross, with a hole at the point where the center of the cross is. We said then that that hole was used to blow out the dust by means of a special compressed-air connection. Well, most drills can replace that compressed-air connection with a water connection, which *flushes* out the rock dust, and at the same time wets it down so that it will not fly around in the air and get breathed in by the workmen. However, when using this water connection, the workmen are bound to become drenched by the water as it sprays out of the drill hole, which opens them to the serious danger of colds. The water method is also sup-



Mud, mud, mud. Rubber boots help keep your feet dry, but sometimes you fall down—and nothing will keep you dry then. Below—A picture of rock leaking. It is just one of the things you take along with your paycheck, when you work in a subway.



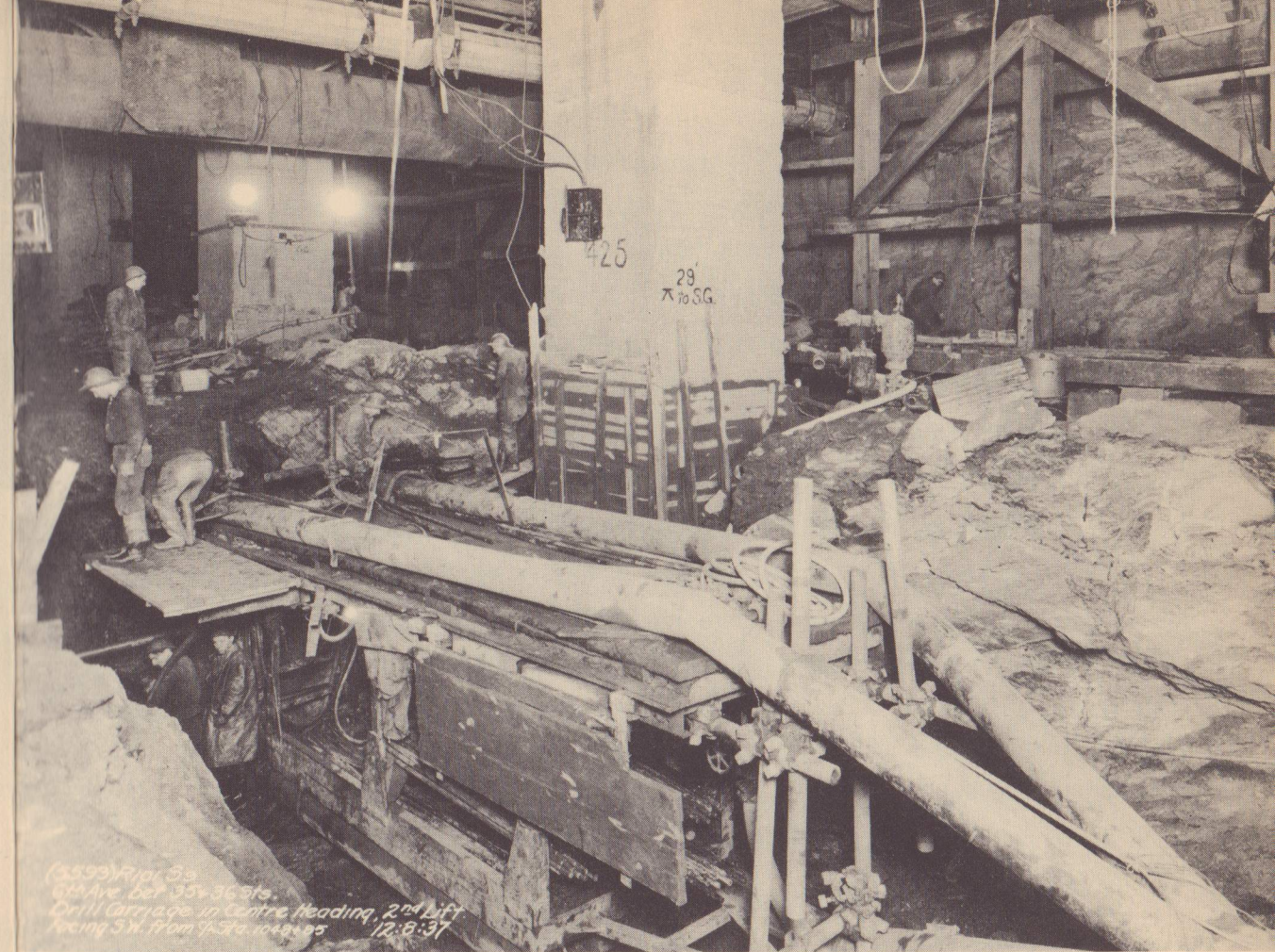
posed to slow down work somewhat. For these reasons, it is not always used, though it really should be.

Another precaution which contractors take is to provide the drillers with approved masks, which furnish them with clean air constantly, and do not permit rock dust to enter. These masks are very heavy and hot and unwieldy to wear, and not every worker will inconvenience himself by putting one of them on. There are lighter and easier-to-wear masks than are usually found in subway work, but they cost more and so are not widely used by contractors.

In rock excavation there is also a water problem, just as there is in earth digging. For rock leaks! It isn't waterproof. There is not likely to be so much mud, of course, but water is a nuisance wherever it is found in subway work. Frequently temporary drains have to be drilled and blasted in the bottom of a rock cut and the water drained to sumps like those in dirt excavation.

It is, of course, just as dark, cold and damp in rock work as it is in earth. And, though you might not think it necessary, in most kinds of rock excavation in New York a great deal of timbering or shoring is needed, just as in the case of dirt work. The reason for this is that much of the rock underlying Manhattan is badly *faulted* and *decomposed*.

Faulted rock has great cracks in it, which may lead at any time to serious rock slides. Decomposed rock is rock which, through the centuries, has become soft and rotten, and it too is not trustworthy. So you will find in many places where rock excavation is being done just as much sheet piling to hold up the sides, and just as much cross-timbering and shoring to support the piling, as in earth digging.



The two huge pipes on top of the big contraption in this picture are used to draw off the rock dust, by means of air suction. Note, incidentally, that the work is being done by "benches" here. In the center they have excavated much further down than at the sides. They will come back later and finish digging out the rock on either side. The first bench was from the top of the rock (all excavated in this picture) down to the level of the remaining rock on both sides of the cut; the second bench is the bottom, where the "drill carriage" is.

Whatever the circumstances, working in a subway cut is very difficult, always very unpleasant, and occasionally quite dangerous. Only the strongest, most iron-constituted and toughest of men take to subway work as a career. But it is a fact that, once a man has it in his blood, he won't take to other kinds of construction work unless he has to. Perhaps this is because it pays pretty well. The crews of men you meet on a typical subway job will include among them workers who have done jobs in subways, tunnels, sewers and the like clear across the length and breadth of our country—and some of them abroad, too.

CHAPTER SIX

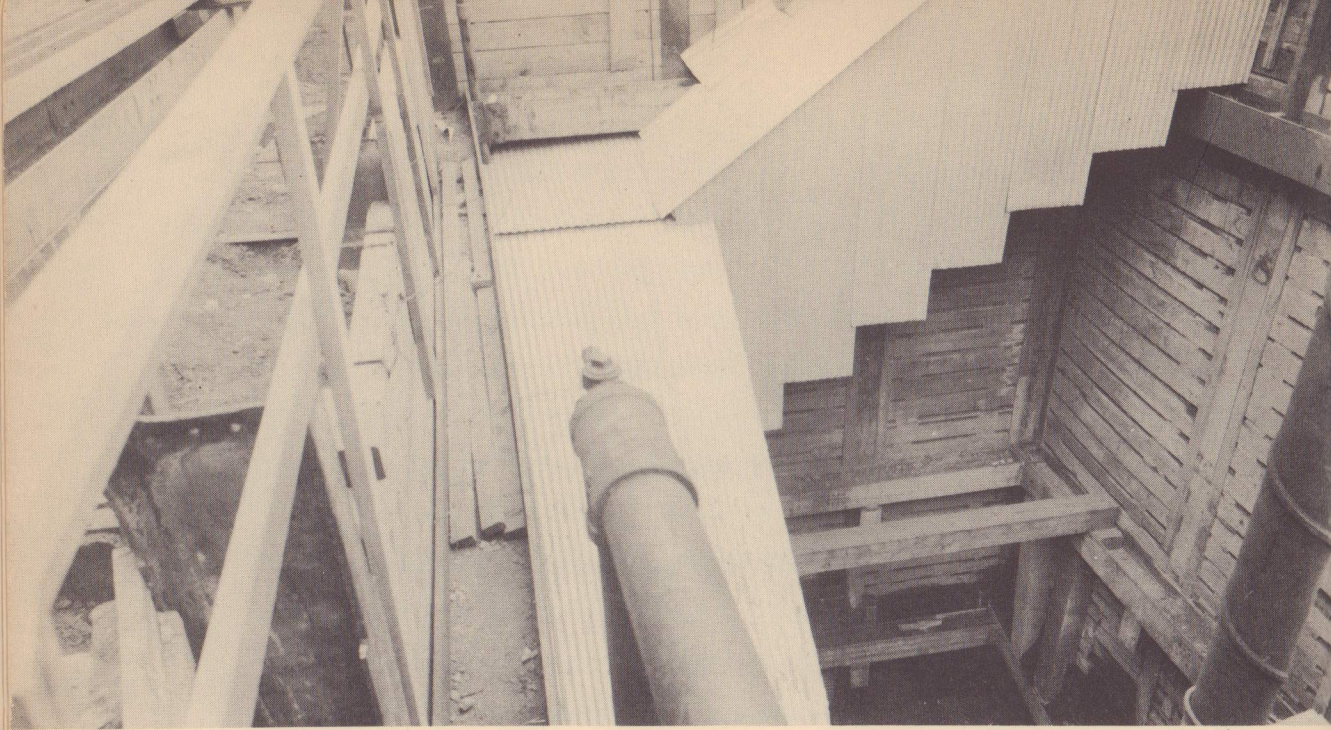
TUNNELING

SOMETIMES sections of the new subway route have to lie so deep under ground that it is not possible to do the work by means of the cut-and-cover method. For instance, the line may have to go under a hill. Or perhaps it must go on a steep downgrade in order to duck under the surface of a valley depression.

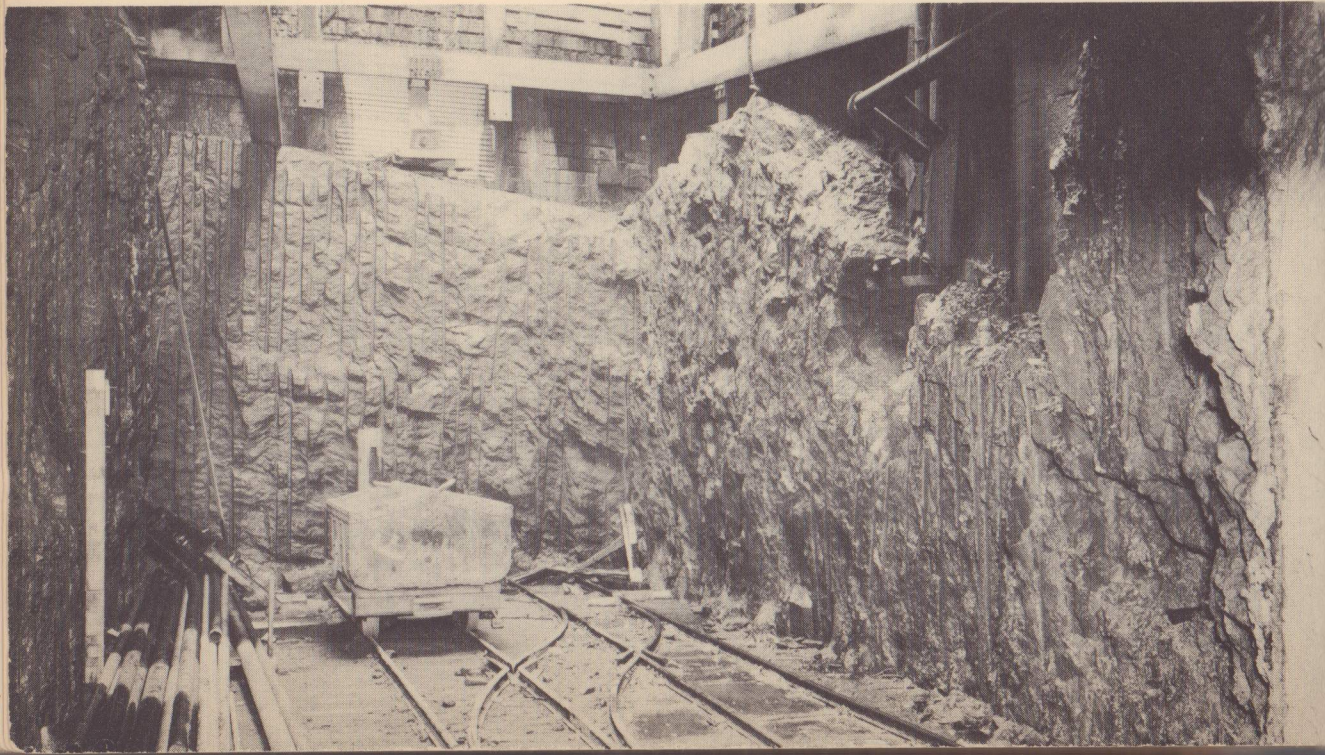
Or suppose the new route has to cross underneath an already existing route. In this case also the work usually involves tunneling, at least when actually going under the tracks of the older line overhead. And there is a fourth and exceptionally difficult occasion when tunneling is the only practical method of construction, and that is when the route has to go under a river. This will be described in the section of this chapter on *shield tunneling*.

Straight rock tunneling, if the rock is in good condition, is one of the simplest methods of subway excavation. No care need be taken of the street surfaces, which are left undisturbed by the driving of a tunnel fifty or sixty feet below the surface. Nor need most of the sub-surface structures and buildings along the street be protected.

Care must be taken, of course, to make sure that there are no serious rock faults or rotted areas down in the tunnel, for if there are, there may be catastrophic slides which would cause dangerous



Above, you're looking down into a tunnel shaft from the top. The corrugated iron passageway clinging to the sides of the shaft is the stairway down which the tunnel muckers go to work. And below is the bottom of the shaft, with industrial track in place and an empty car waiting to be pulled back to the heading where work is going on.



settling of buildings overhead, the breaking of pipes and wires in the maze of subsurface structures, and similar accidents. To avoid this the rock in the tunnel is constantly tested for firmness and, if any weak spots are found, they are strongly shored up with timber, steel or concrete piers.

The tunneling itself is one continuous process of drilling, blasting, cleaning away—drilling, blasting, cleaning away. A large shaft is blasted down to the tunnel level—big enough to admit the entrance of sizable machinery, even including small power shovels. If possible, this shaft is located on the piece of property where the contractor has his shops and his working field office. The same method is used as in rock dynamiting in cut-and-cover work, except that heavier charges can be used since the tunnel is deep under ground.

As in the case of blasting nearer the surface, however, no blast is ever set off until it is made absolutely sure that every man in the whole area is safely out of the way. For anyone near the blasting area might be killed by flying rock or seriously injured by the shock of the explosion itself.

After the shaft has been driven and a horizontal tunnel blasted in the rock where the exact line of the new subway is to be, the surveyors of the Board of Transportation check the work to make sure that the heading of the new tunnel is exactly in line with their carefully surveyed station marks far above on the sidewalk, and at the exact depth called for on the contract drawings. Then blasting and drilling begins along through the area where the regular tunnel is to go.

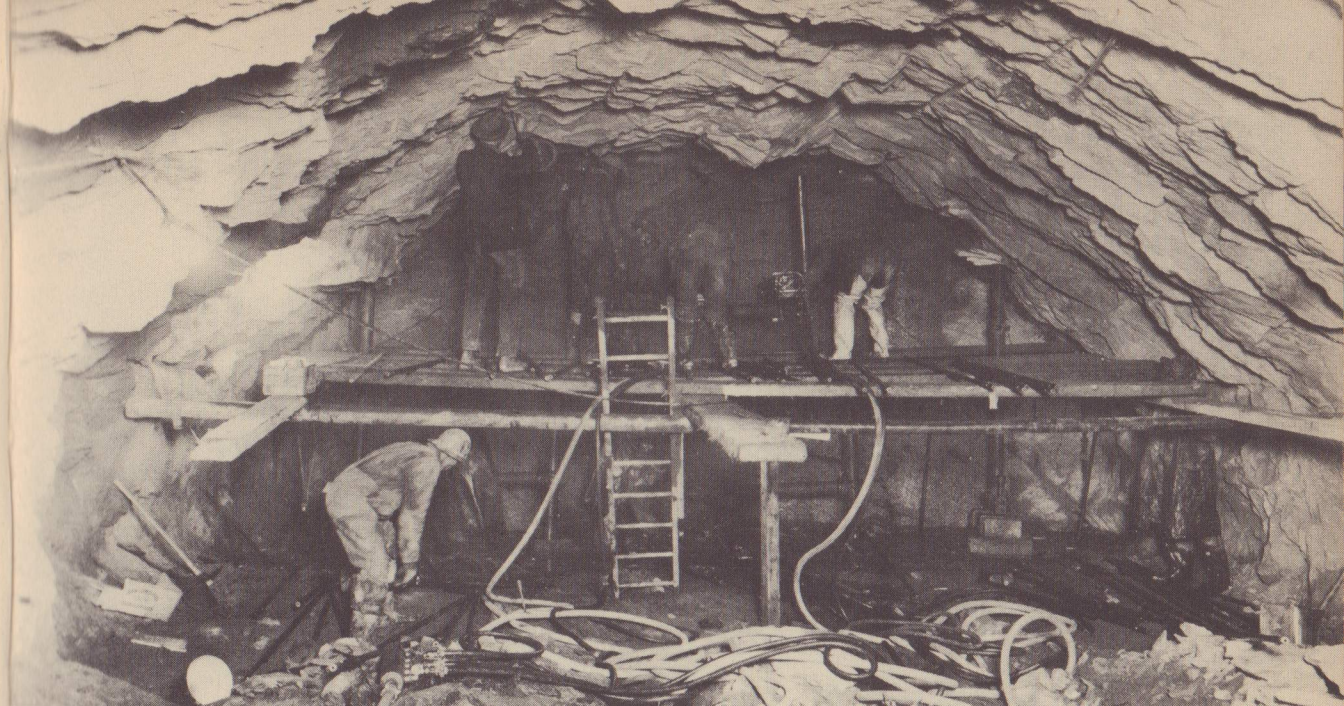
There may be from four to twenty men at the tunnel heading, drilling holes from two to four feet deep, in which the heavy charges of dynamite will be placed. Here far under the surface of the earth the

noise is worse, if possible, than it was up nearer the street level. The dust menace is so serious that special methods of drawing it off by means of complicated air fresheners have been developed, in addition to the use of water streams in the drills, and masks for the men.

And so the work progresses. As the tunnel heading recedes farther and farther into the rock, away from the working shaft, most contractors lay *industrial track* from the shaft to the heading. This is a tiny railway track with a gauge, or width, of about two feet. The rock pieces are piled onto buckets which rest on car trucks running on this industrial track. When a bucket is full, the car on which it rests is pulled from the heading to the shaft by means of storage-battery engines. At the shaft, an enormously powerful electric or Diesel crane way up on the surface sends its hook down below; and workmen fasten this hook to the rock-filled bucket. The bucket is then lifted off the car truck, up to the surface, and is dumped there into waiting motor trucks.

In these deep tunnels there is always a water problem, even though the rock may be *monolithic*—meaning, solid and all of one piece. Water will seep through cracks and seams even in such rock. This water is removed through special drainage ditches, which lead to temporary sumps, much in the same way as draining a cut-and-cover job.

However, this water condition makes tunnel work much colder and danker than work on the surface, for far down in the tunnel there is little possibility for warm street air to enter. In many cases special air-conditioning systems have to be used, especially if the tunnel is long. In other cases, the contractor may have *air vents* bored from the street surface clear down to the tunnel, every few hundred feet. This allows some fresh air to enter—but not enough to keep the tunnel warm.



Straight rock tunneling, without even much water to bother you. Here (above) the tunnel is going to be so high and wide that the men can work on two levels—one on the ground, and one on a platform. Below—A much smaller tunnel. The rock is badly faulted, and temporary overhead shoring is needed near the heading to protect the workers from falling boulders, and also from collapse of the side walls.





Industrial track. The storage battery engine is above. It goes very quietly, of course, and not very fast. Below, one of the miniature power shovels which have been specially designed for small tunnel work, busy loading rock into a bucket on an industrial-track car.



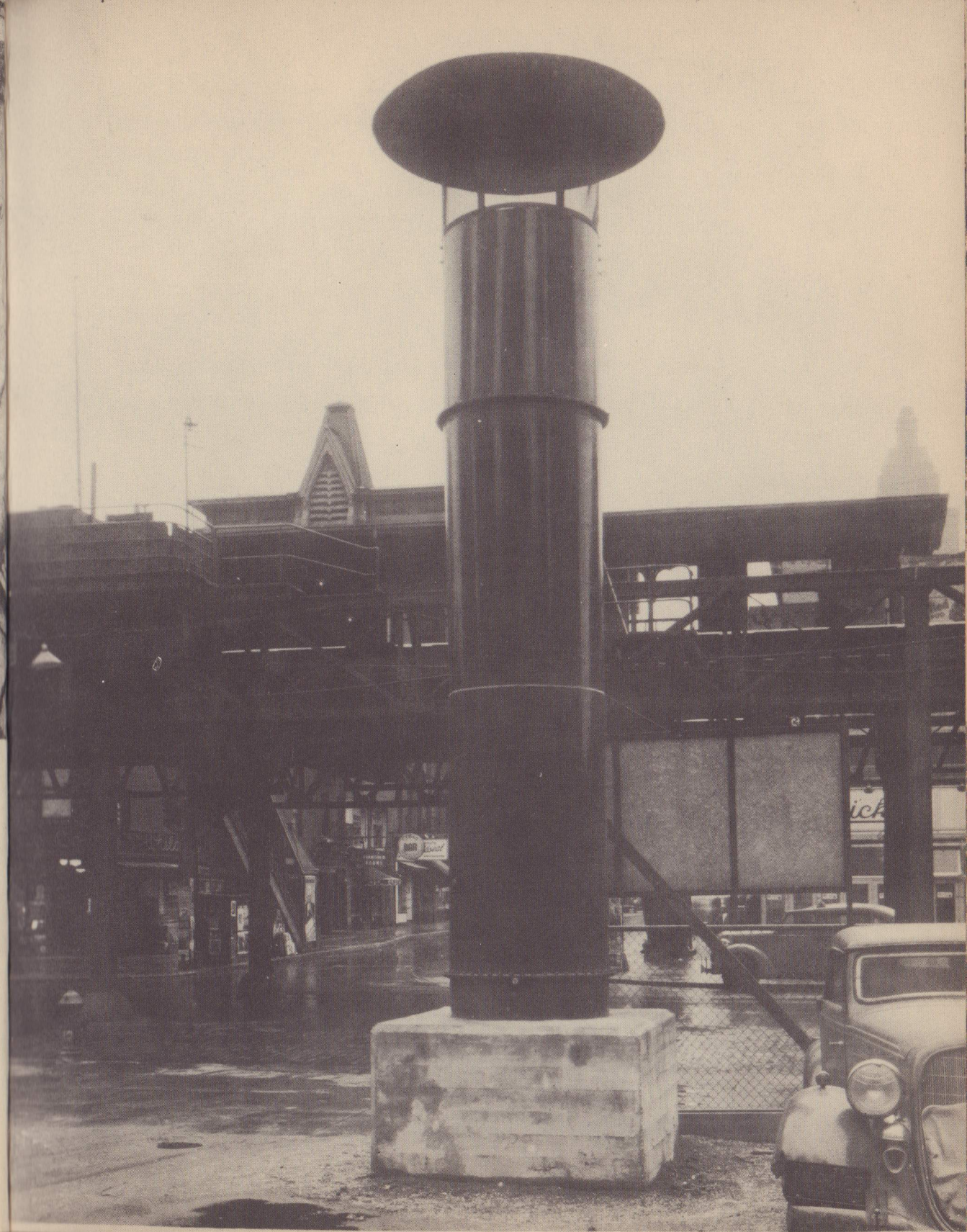
A rock tunnel has sprung a very serious leak. Note the sandbags used to hold the water and mud back. What actually happened here was that the contractor had to change his plans and change from straight rock tunneling to shield tunneling under air pressure. The test borings made at the beginning of the job did not show the break in the rock formation which caused this leak.



(1622) R107-512
N.E. TUNNEL
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2-16-29

Here is just about the way it is in tunneling. It is nearly as wet as if you were in swimming—and a lot more uncomfortable. Gloomy, cold and very definitely frightening, what with the possibility of a boulder landing on your head at any moment.

Facing page—In very deep tunnels some contractors use fresh air under small constant pressure to keep the tunnel air breathable. This tall "air-tower" is used to get fresh air, which is drawn into it by means of suction pumps, and which is then distributed through the tunnel by means of tin piping. It is also used for compressed-air shield tunneling (see next section). (Courtesy Spencer, White and Prentis.)



These underground tunnels range in size from small ones measuring perhaps only eighteen feet in diameter for a single track, up to huge fifty- or sixty-foot-wide tunnels where four tracks, or two tracks and a station, are to be located. Thousands of tons of dynamite are used in these enormous blasting jobs.

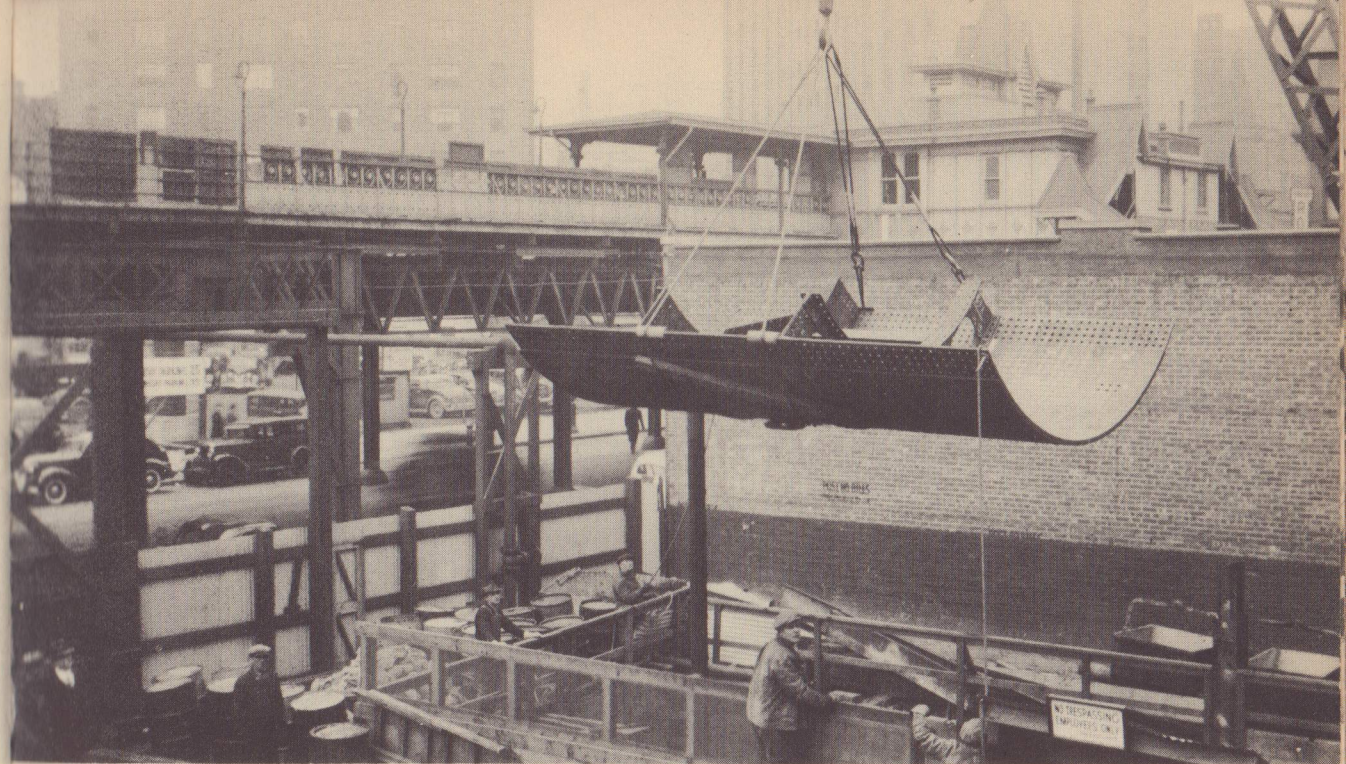
SHIELD TUNNELING

In shield tunneling, methods of excavation are the same as in regular tunneling. When blasting is required, it is done with much smaller charges, of course, but the same techniques are used.

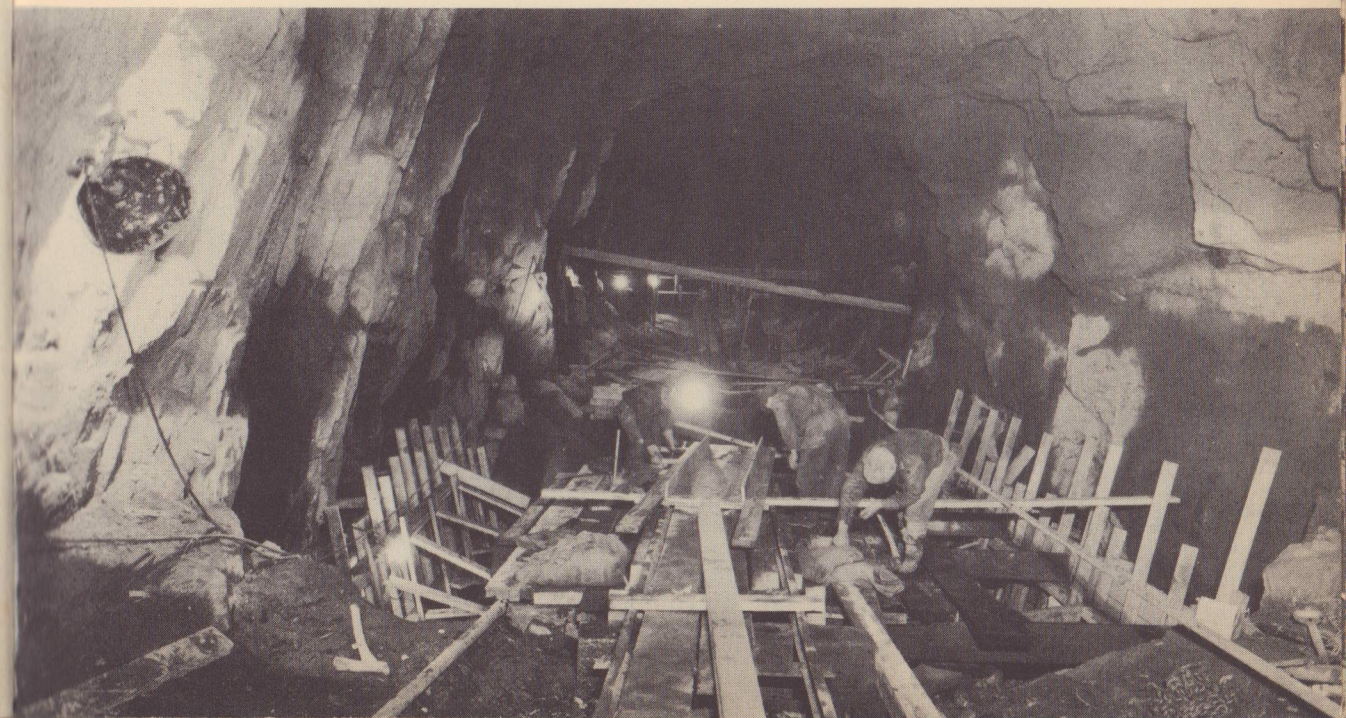
But how different the working conditions, and how different, indeed, the whole procedure! Shield tunneling is perhaps the most difficult, dangerous and unhealthy work man has yet undertaken, with the exception of certain types of mining.

In a great majority of the cases where shields are needed in tunneling, the workmen have to labor under a heavy air pressure, which is used to keep out the weight of the water-filled silt which lies directly over the tunnel when it is going under a river.

It sometimes happens that the shield method also has to be used in land tunneling. Usually this happens only when the ground to be tunneled through is badly decomposed rock, or very wet earth or sand which lies below ground-water level. Ground-water level is that place under ground where water begins seeping through sand or rock. Conditions are about the same whether shield tunneling is done on land or under water, except that the air pressure on land is much lighter than it has to be under rivers.



A section of the shield being lowered down the tunnel shaft. It will be assembled with the rest of its part in the "shield pit," which is shown being dug in the tunnel, in the picture below. (Top photo, courtesy of Spencer, White and Prentis.)



The shield itself, pictures of which are to be found on the following pages, is an absolutely air-tight piece of complicated steel construction, which is fitted closely in at the heading of the tunnel.

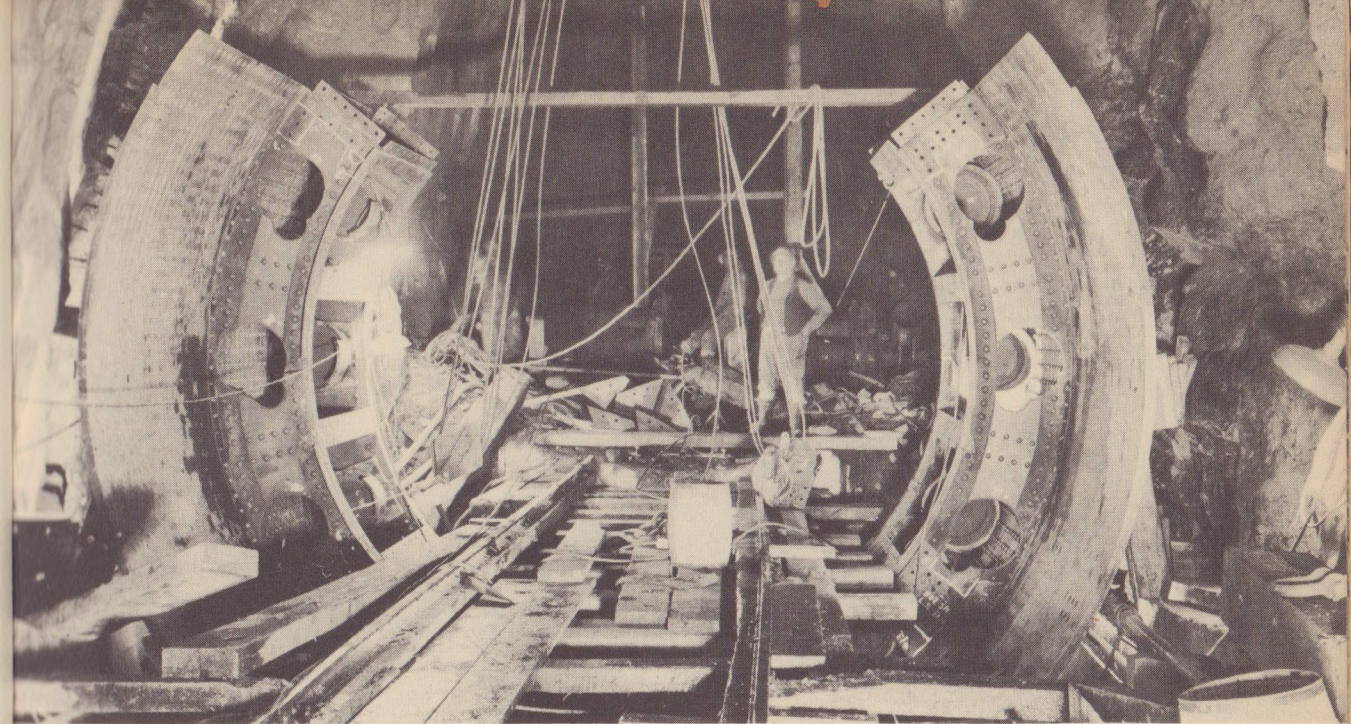
These shields are always taken into a tunnel piecemeal and put together in a specially prepared *shield pit* as near to the point of excavation as possible. It would take a whole book to give you a detailed description of a shield and how it works—all we can attempt here is a brief outline of the apparatus itself and its function.

A shield is a circular steel and cast iron ring, the inside diameter of which must be large enough to permit the actual tunnel segments to be constructed inside it—in other words, the shield has to be larger than the tunnel itself is going to be. As a matter of fact, the *inside* dimensions of the *rear* of the shield must be *exactly* the same as the *outside* circumference of the tunnel itself.

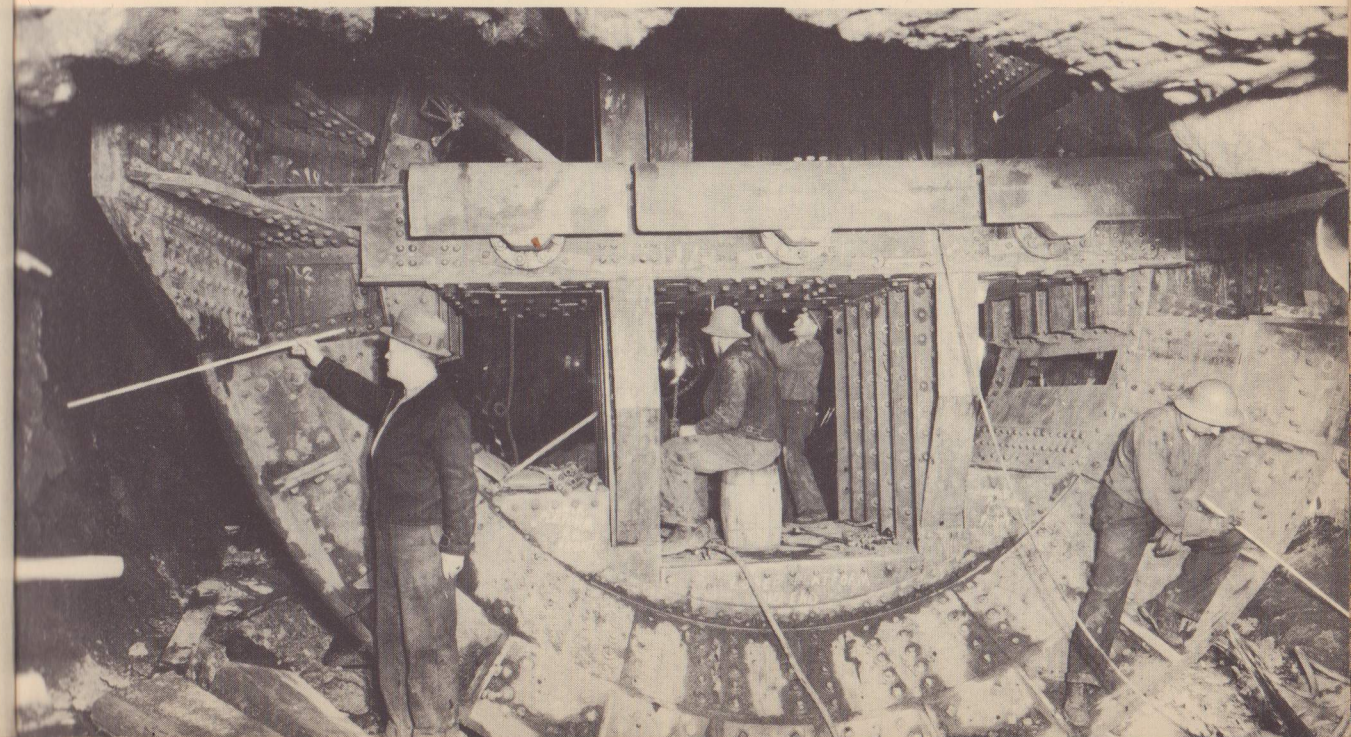
The *front* of the shield is the end facing the excavation. It is through the front end that the men dig the earth or blast the rock. Do not forget that the reason for the use of the shield is the presence of large amounts of water, which is kept out of the shield only by the pressure of the air in the shield compartment. The excavation in here is exceptionally muddy and wet.

The upper half of the shield's front is called the *hood*. It projects about three feet beyond the bottom half, so that the men working there are protected from the danger of falling rock or earth which might otherwise crash down on them.

There are two *working decks*, as you can see in the photograph—the top deck is the one in the upper half of the shield; and the bottom is the one in the curved lower half. On the upper deck work is done by means of a *retractable platform*, which is a part of the top working



Erecting the shield in the shield pit (above). Here only a part of the outer shell is yet in place; but the photo below shows the work much farther advanced. The center supports are in place, and the hood can be seen above the center of the picture at the far left. The men are checking with foot-rules the distance between the outer face of the shield and the rock wall. (Top photo, courtesy of Spencer, White and Prentis.)



deck that can be pushed out to the face of the hood in order that the upper half of the area may be excavated. Then this platform can be pushed back into the top working deck so that men can come out through the bottom deck to excavate the bottom half of the area.

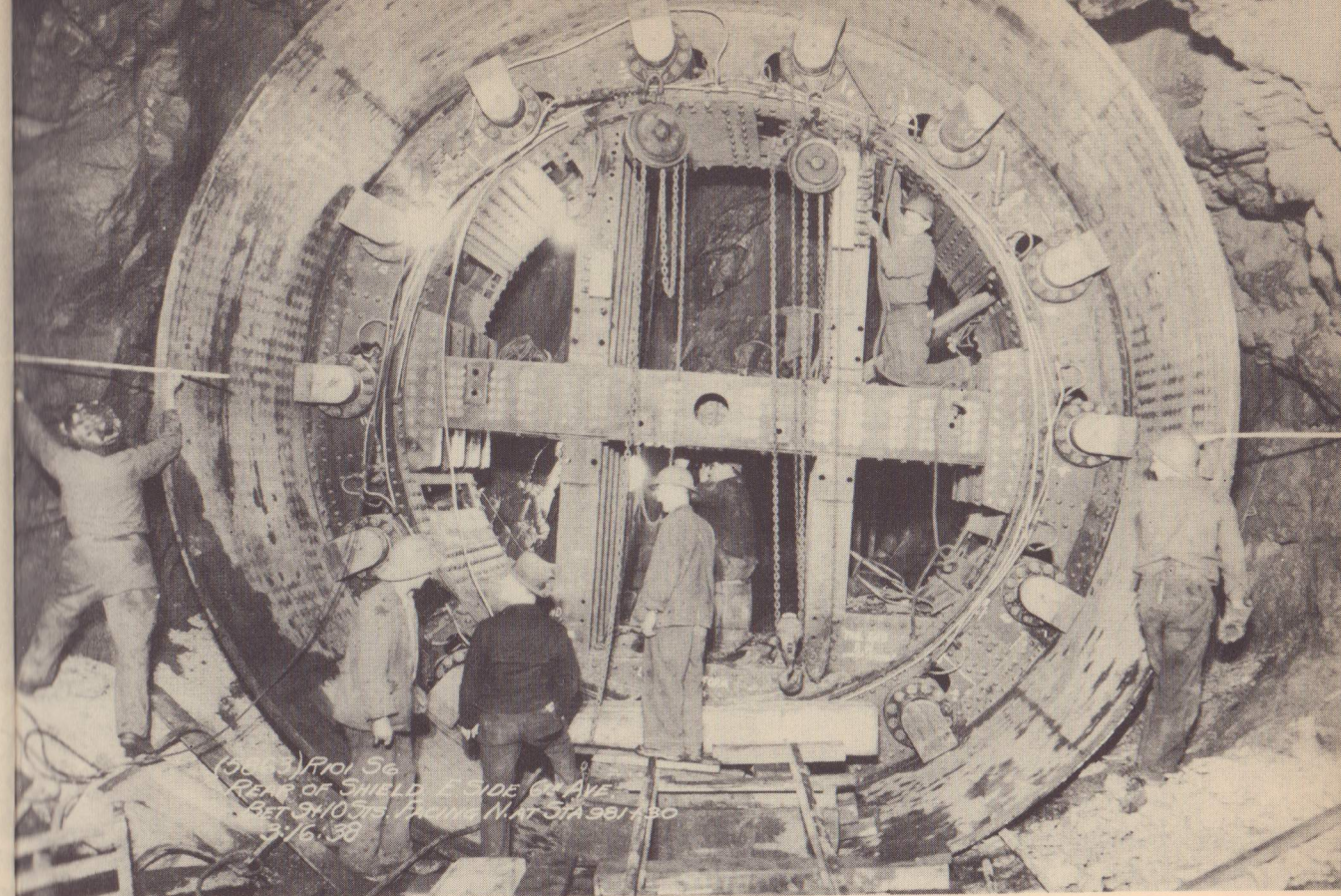
When shield tunneling is done through wet earth and sand, strong *breast boards* are always set up to keep the material from caving in. One or two of these boards are removed from the place where men are digging, while the rest of the boards keep them from being swamped by an intruding mass of earth.

In the bottom picture on page 115 you see three *hydraulic jacks* in the floor of the top deck. These jacks, and additional portable *trench jacks* are used to hold the breast boards in place. No one who hasn't worked in a shield can have an idea of the pressure exerted by the wet earth and sand against these jacks—it is tremendous! If the jacks and the breast boards they support should give way, the whole tunnel might be flooded with mud and water.

A hydraulic jack is, of course, operated by water under high pressure—not by compressed air. A hydraulic system is a dozen times more efficient in operating these jacks than a compressed-air system could be.

The body of the shield, which contains the enormously heavy steel top deck and the two vertical steel walls, is used as a means of getting out to the front of the shield. However, its real purpose is to hold up a tremendous weight of material which otherwise would fill the tunnel. It is the strongest part of the shield, the part which makes it possible to dig under a weight of earth and water sometimes amounting to thousands of tons.

The rear, or *tail*, of the shield is also of great importance. It is a smooth circular steel tube about seven feet long. Built up in the center

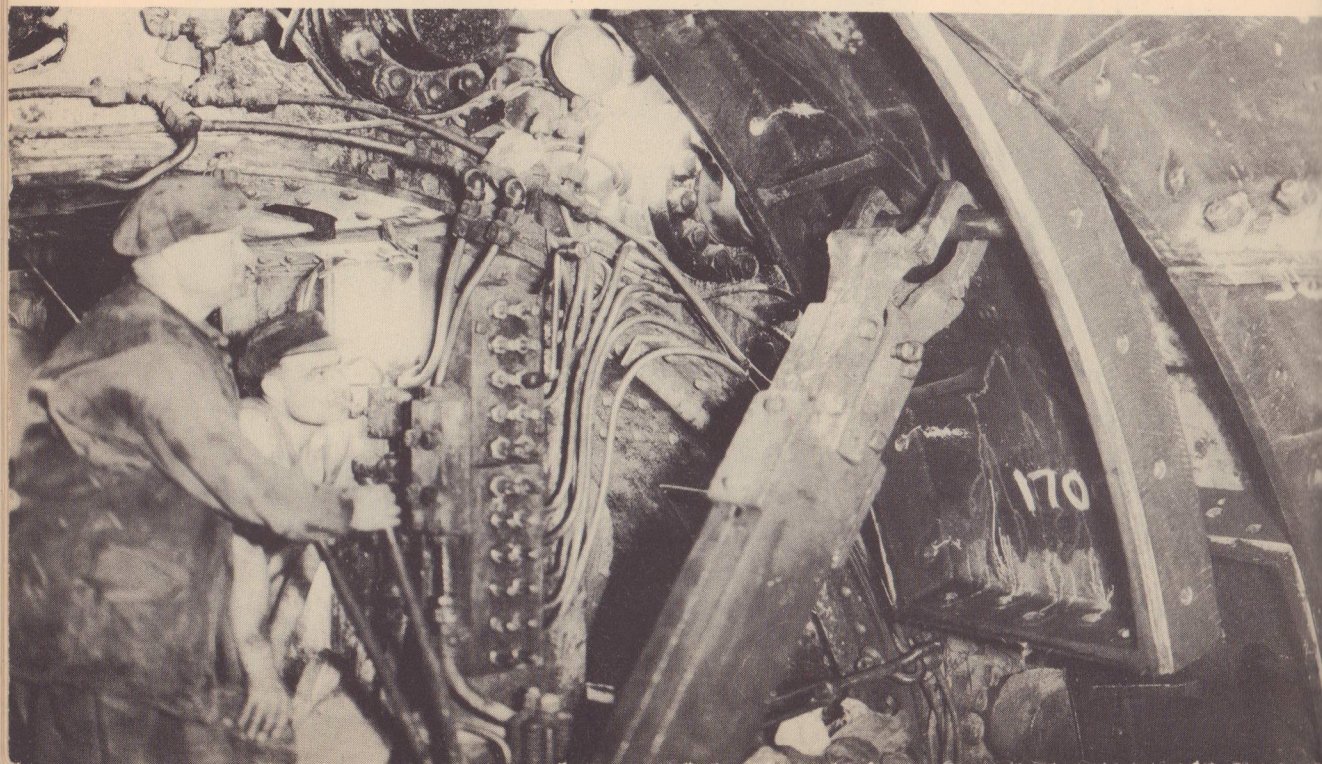


The shield from the rear. The "tail" is the part which sticks out beyond the main part of the structure; and those queer objects placed about two feet apart all around the shield inside the tail are the hydraulic jacks used to push the shield ahead. Below is the way the shield, as assembled, looked from a distance.





Now the air is on, and the system is working. The breast boards (above) hold back the wet earth while the men (barely visible in the lower right-hand corner of the picture) excavate from the lower part of the shield. Below, the erector arm of the shield is being operated, and is putting one of the one-ton sections of tunnel ring into place.



of it is the *erector arm* for putting up the actual cast iron or steel segments of the permanent tunnel itself. This is really a very small crane which lifts and holds a segment in place against the outer wall of the shield, until it has been securely bolted to the next adjoining completed ring and to the segment which the arm has just put in place.

A typical small tunnel section consists of eight segments, each of which weighs a ton or more and measures thirty-two inches in width. These segments, together with a much smaller piece called the *key*, form a complete circular *ring* when strongly bolted together and caulked with lead or some such substance against the inflow of water or mud. Rings in larger tunnels are made of a greater number of much bigger segments, but in every case the principle is the same. This is the only occasion in subway work when the main part of the subway structure itself is built at the same time that the excavation is done.

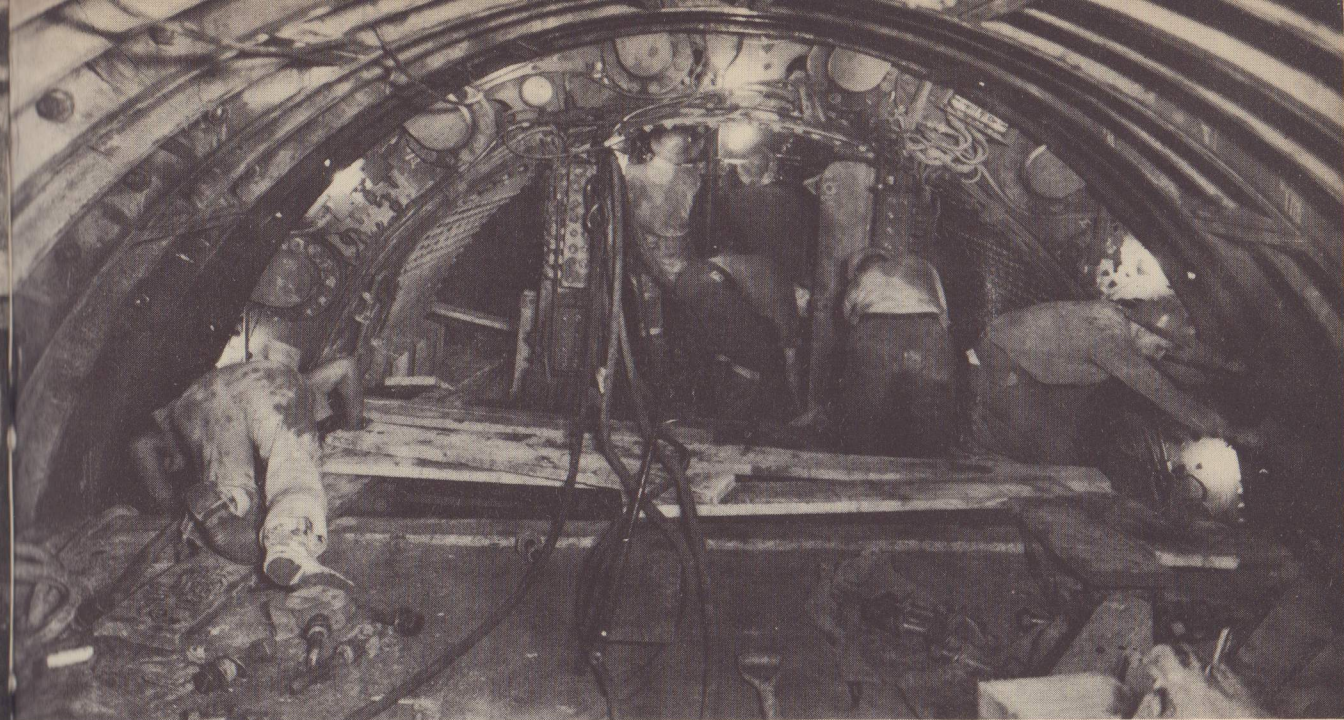
These tunnel segments are so carefully designed and machined that they fit together with absolute exactness. The rings are made in steel or iron fabricating plants far from the actual job—perhaps in another state. The contractor has furnished the steel or iron mill with minutely accurate drawings of the tunnel rings, and the rings were cast to specifications. When a tunnel has to turn a corner or go up or down a hill, these rings must be specially and individually designed so that each one will *taper* enough to cause the correct curve, or uphill or downhill turn. The rings used in making a tunnel rise, fall, or curve are called *taper rings* because they are so made that, when a series of them is fitted together, they make a curved instead of a straight tube.

Another part of the tail is fourteen or more strong hydraulic jacks, so placed that they bear upon the last-placed tunnel ring. When a ring

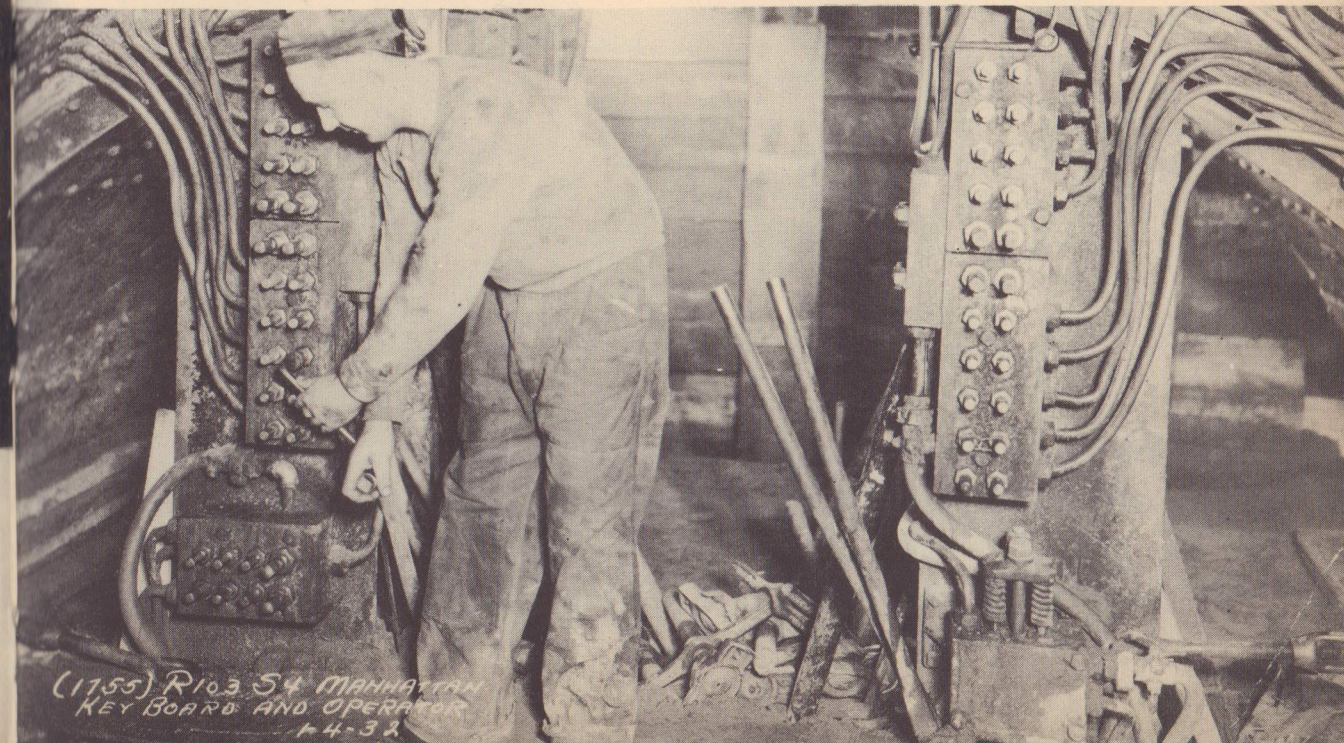


(1736) R103 S4
N.W. TUNNEL SHIELD RING #125.
12-2-31

Once a ring has been lifted into place and temporarily fastened with bolts, the erector arm lowers, and men come down to the area with their huge bolt fasteners. Here they are tightening the nuts on the enormous bolts used to fasten the sections of the ring together. Note their state of undress—it must be hot in there where they're working!



Above—A crew of drillers preparing holes in the rock in front of the shield for blasting. Everyone will get out of the air compartment when the blast is shot off, of course. Then, after all the material is cleaned out, the hydraulic jacks are turned on and the shield inches ahead under the enormous pressure of the jacks. In the picture below you see the "key-board" which regulates the various pressures of each jack.



(1755) R103 S4 MANHATTAN
KEY BOARD AND OPERATOR
1-4-32

has been completed, these jacks are slowly turned on and, pushing with immense force against the ring, shove the shield out into the space ahead of the tunnel which has already been excavated by the mucking crews working in the front of the shield.

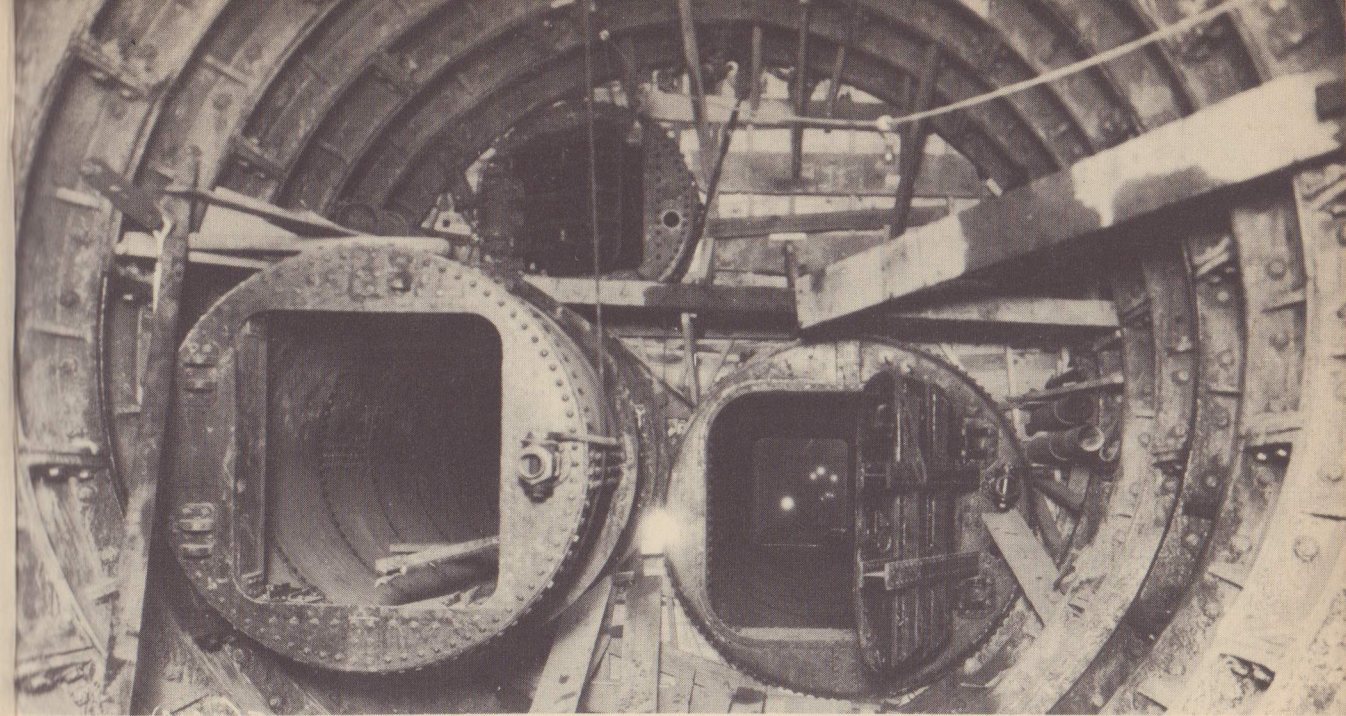
WORKING "IN AIR"

The purpose of a shield, as we learned before, is to form one end of an absolutely air-tight compartment. It is the working end—the end which can move out as excavation and tunnel construction proceed.

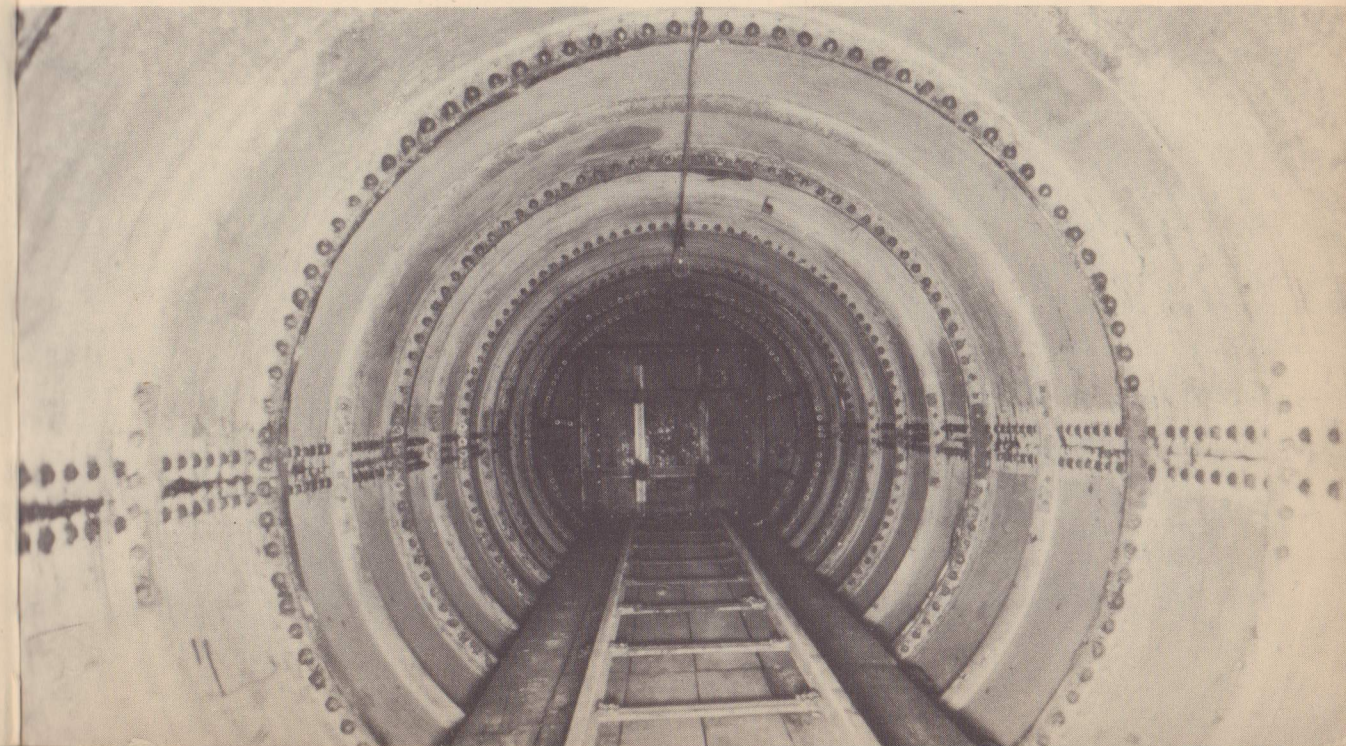
The other end—the end at which work was first begun—has been built up with a solid concrete *bulkhead*, or very thick and strong wall, filling the whole tunnel and acting as a solid block to keep up the air pressure between it and the shield. When this bulkhead was built, three *locks* were embedded in it. These locks are large, heavy steel tubes, resembling huge boilers big enough to hold twenty or thirty men or a short train of the dump carts which carry broken rock and muck away from the face of the shield where excavation is proceeding.

The three locks are known as the *muck lock* (the largest and the one used for muck trains); the *man lock* (the one in which men must sit before going into or out of the air-pressure section of the tunnel); and the *emergency lock* high at the top of the bulkhead, which is of about the same size as the man lock. In larger shield operations there may be two or three muck locks, and much bigger man locks and emergency locks.

The necessity for these locks is quite obvious. You could not open the door into the air-pressure chamber without having all the air



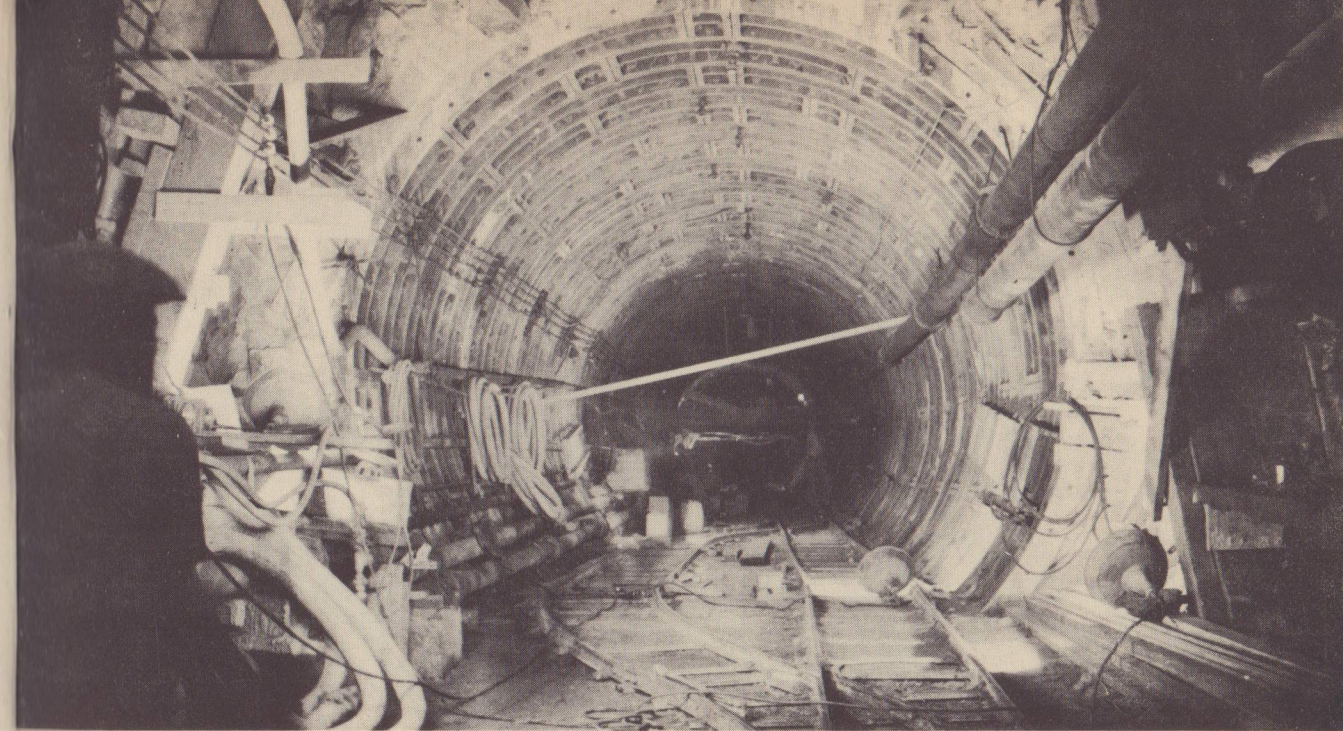
The series of locks are in place, but the air pressure has not yet been put on, in the photo above. You can see through the muck lock at the right out into the rock tunnel. But from this point on the lock will always be closed, either at one or the other end, in order to keep the high air pressure up in the shield compartment. Below—The inside of the muck lock. (Bottom photo, courtesy of Spencer, White and Prentis.)



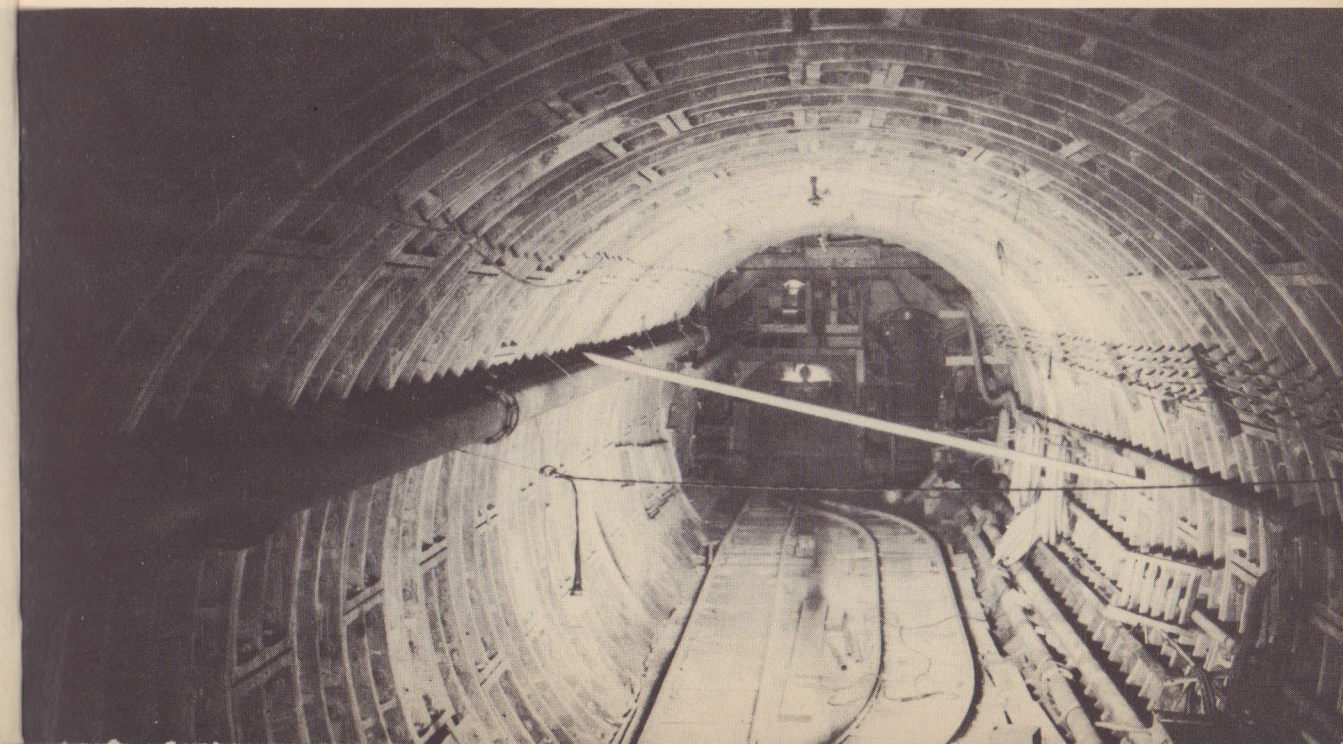
escape with the force of an explosion. Moreover, no man could either come into or go out of a compressed-air chamber into a normal air pressure without becoming very sick. So every time the workmen go into the air-pressure part of the tunnel they have to sit in the man lock, with the outer door closed, and wait until the lock tender manipulates the air valves to permit the compressed air to come slowly into the lock—until the air is of the same pressure as inside the working compartment. If the men have been careful and have strong constitutions, no colds and no clogging in their ears, they can take this increased air pressure without too much discomfort. Then they can drill, dig, erect tunnel segments, bolt them together, and so on, in the air-pressure working compartment.

The muck lock is regulated automatically by men outside of it. No workmen ever pass through this muck lock and there is no need to regulate the air pressure. When a train of empty cars is to go into the compressed-air section, it is locked in the muck lock and the full amount of air pressure in the working section is immediately admitted to it. Similarly, when a full train is to come out of the muck lock, the air pressure is released instantaneously with a roar that would wake the dead. The door of the lock opening into the normal air-pressure area of the tunnel opens automatically and the train is pulled off to the shaft where the crane lifts the muck cars and dumps them.

The emergency lock, located high at the top of the bulkhead, is for use, as you can gather from its name, only in case of dangerous accidents and emergencies, such as floods. For instance, in the case of a flood, the crew working inside can rush up to a catwalk suspended from the roof of a tunnel, many feet above the floor, and hasten into the emergency lock while down below water may be pouring in at a



Here is the way it looks inside the air compartment. Above, a view taken near the locks, looking toward the shield; and below, a view from the shield looking toward the locks. (Both photos, courtesy of D. M. Brown.)



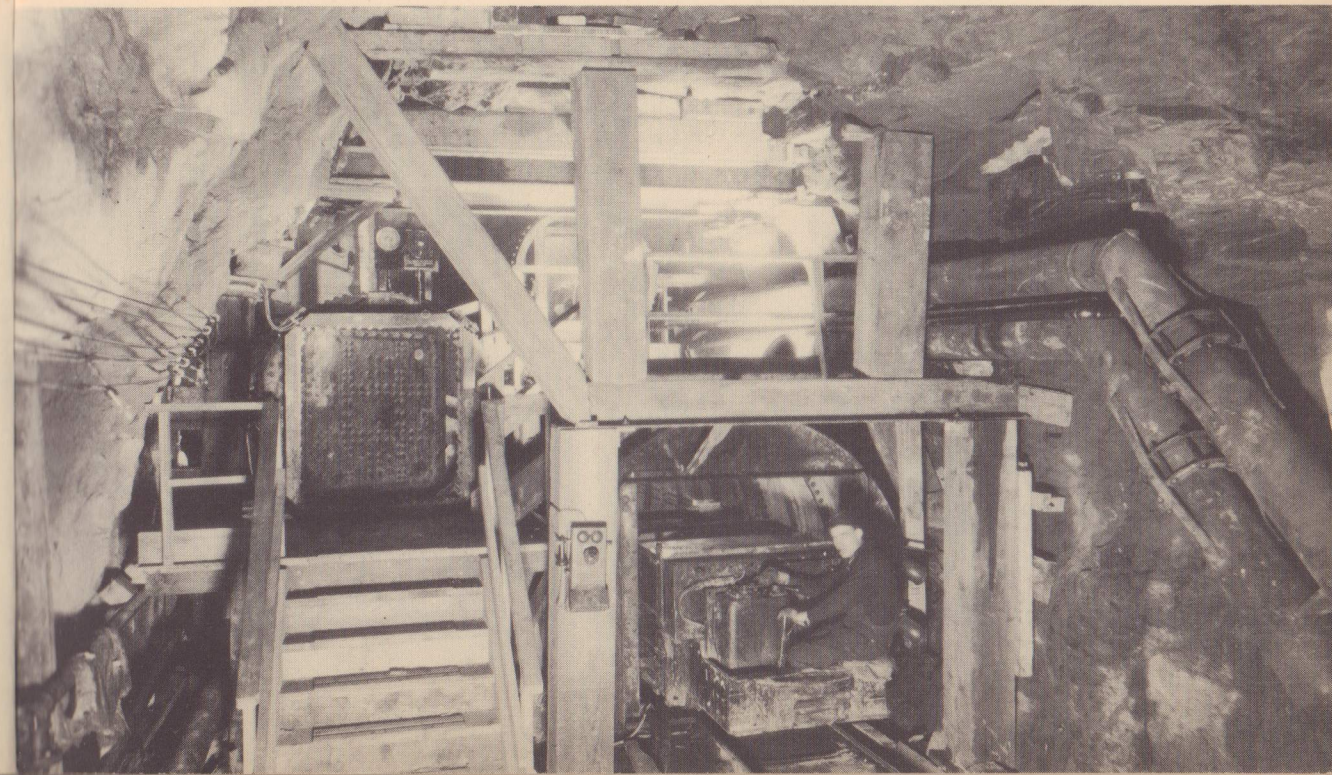
rate of thousands of gallons a minute. The emergency lock is required by law, and many are the lives its presence has saved. Its use is called for mostly in the case of tunneling under rivers, when accidents cannot be helped at times and the whole river may begin to rush into the tunnel. This happens extremely rarely, of course, but if it does, the emergency lock is a way out of the trap in which the men would otherwise be caught.

Surprisingly enough, though it may be miserably cold and dank outside in the normal air pressure, here in the compressed air it is extremely hot, since air under pressure heats up to quite high temperatures. The workmen sweat and steam at a great rate and perspiration breaks out all over you even if you just sit and watch them. Because of this heat and the danger in being subjected to heavy pressure of air for long periods of time, people who work "in air," as the workers themselves refer to compressed-air jobs, only work for stretches of time ranging from three or four hours down to an hour. They come out then, rest for several hours, and then go back to work another shift. The heavier the air pressure, the less time the average man can spend working in it.

Coming out of the compressed-air compartment through the man lock, the workers have to stay in the lock much longer periods than before going in—seven minutes for even the lightest pressure of ten or fifteen pounds per square inch, and up to half an hour or more under pressures of forty to fifty pounds, which is about all that a human being can stand. If they should come out too fast, they will get a very painful and dangerous disease, known as *the bends*. This disease is caused by bubbles of air forming in the blood and, though not often fatal, it is sufficient to cripple men for life. Exceptional care is always



After working for the two or three hours their shift lasts, the men (above) are coming out of the man-lock. Now they'll go off and drink lots of hot coffee and rest up for an hour or so before going on for another two or three hour shift. Below, an engine preparing to pull a loaded car out of the muck-lock. (Bottom photo, courtesy of Spencer, White and Prentis.)



taken that *decompression* (coming out of compressed air into normal air) is brought about at a safely slow and even rate. This disease appears more and more rarely in modern tunnel work.

Working "in air" is obviously no job for weaklings. If every man who works in subway construction must be hale and hearty, strong and firm of heart and lungs, men working "in air" must be doubly so.

CHAPTER SEVEN

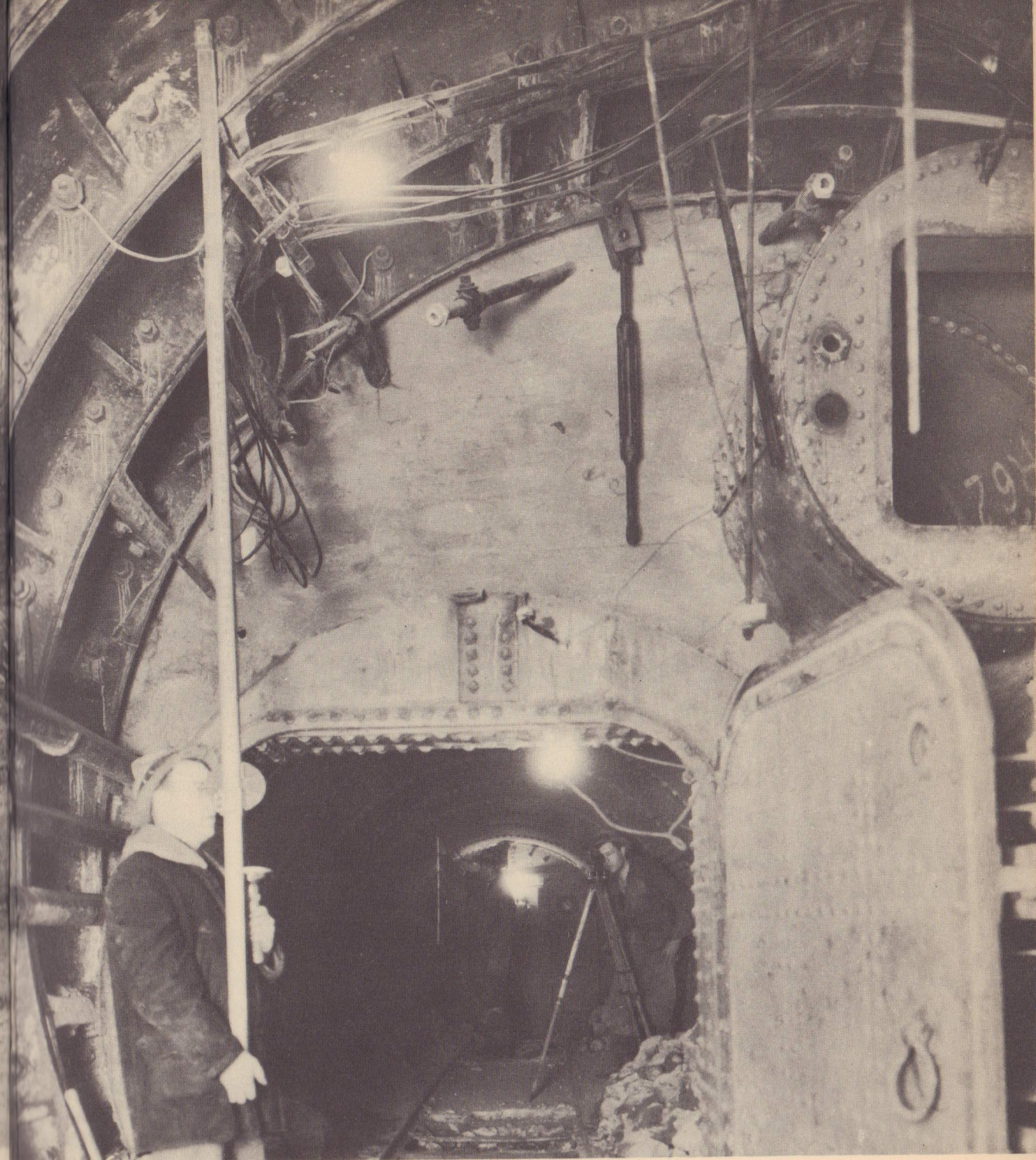
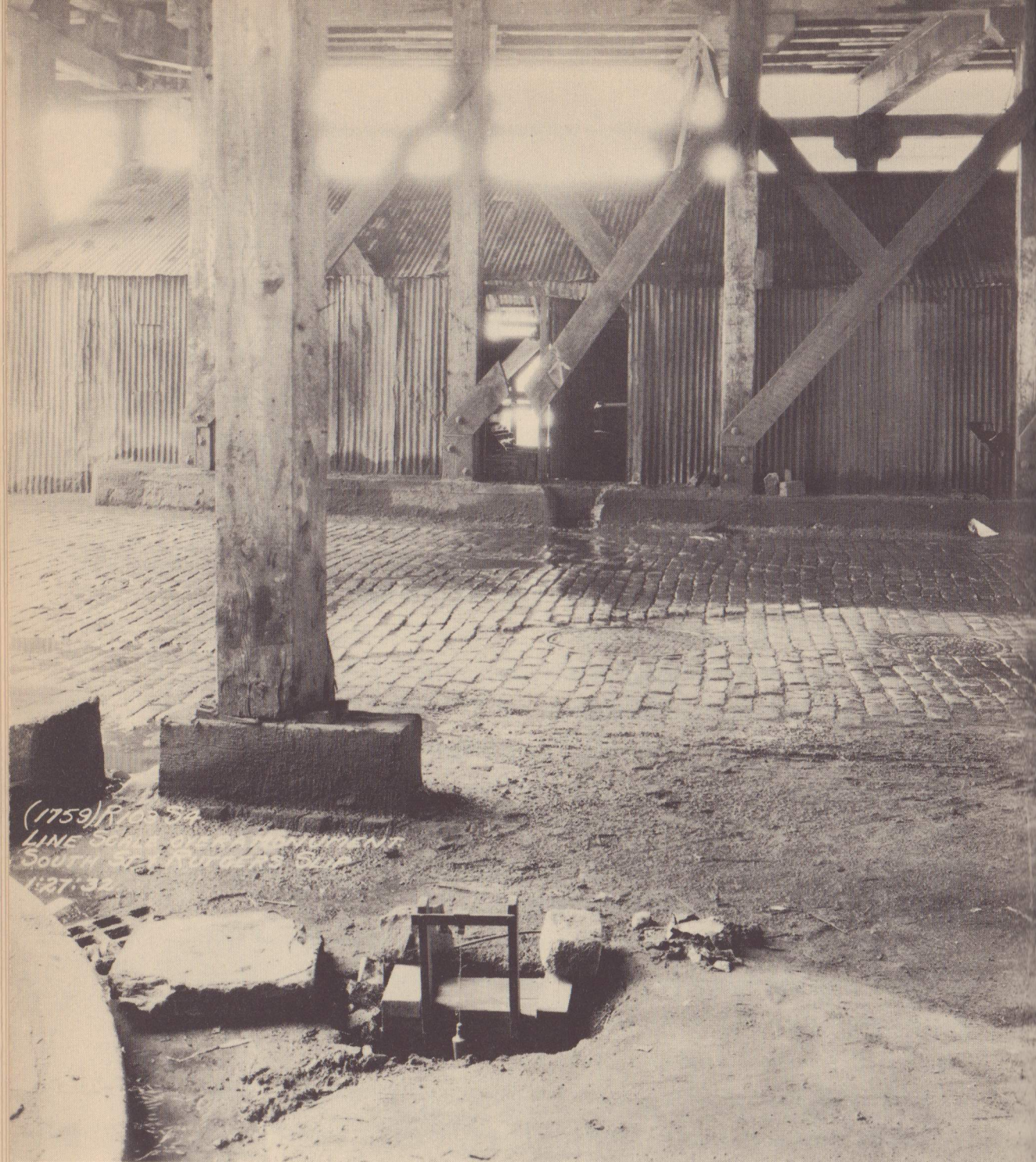
CONSTRUCTION

AT LAST, after many months of digging and shoring, boring and blasting and mucking, and, in cut-and-cover construction, underpinning and caring for subsurface structures, a section of excavation running for several blocks is more or less complete down to subgrade. The shield-driven tunnel is completely lined with its outer rings of heavy iron; the rock tunnel is a great, long cave, cold and echoing.

The Board of Transportation surveyors now complete their careful checks of subgrade levels. They have approved the uphill or downhill gradients, and the curves in the subway cut. They have transferred, by complicated systems of measurement, the original stations that had first been measured when they prepared their baseline maps, down through the decking or through holes bored down to the tunnel, so that they are now carefully marked in the subway itself, on a pier, a supporting girder, or a convenient rock.

Though the actual excavation for a subway is the main part of the job, it is only the rough preparation for the finished structure. It is this structure that most of the Board of Transportation contract drawings, specifications and estimates deal with.

A hundred and one things must be considered in designing this permanent subway structure. It must be strong, correctly proportioned



Surveyors checking their stations and dropping them underground.
Above—The street location of a previously-measured station

and here, the surveyors are transferring the exact location of that station
far down into tunnel—and actually measuring it through a muck-lock and
into a shield compartment!

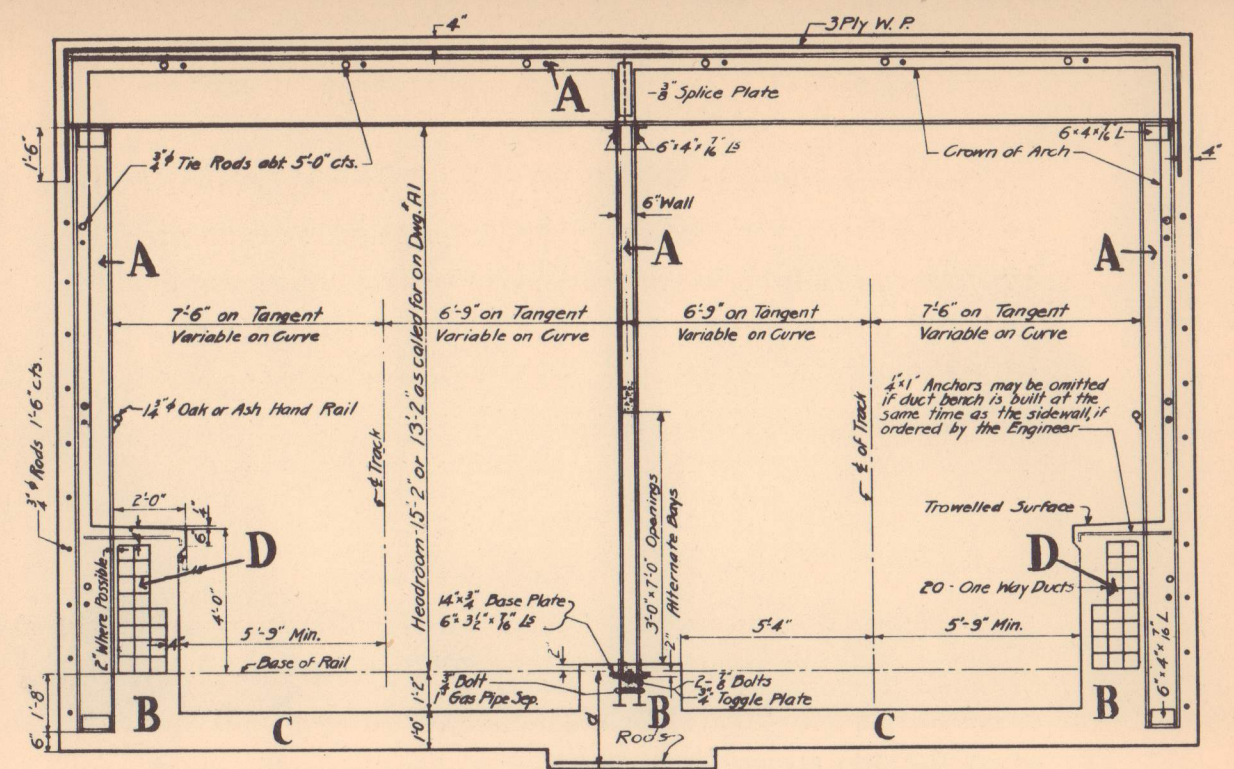
and waterproof. It must be designed to carry the weight of the traffic on the roadway overhead; the sidewall weight of the earth or rock; the tremendous loads of the various subsurface structures; and the vibrating, rushing weight of ten-car trains fully loaded with thousands of passengers. The specifications made by the Board's engineers take into consideration all these things.

STEEL

As soon as the contractor receives the working drawings, sometimes even before actual excavation has started, his structural steel experts begin to work in close communication with the steel mill to which he has sublet the contract for making steel girders, bolts, cross-beams and all the other miscellaneous metal necessary in a subway structure.

Every rivet hole, every fraction of an inch of length or breadth, every pound of expected stress and strain, has been minutely marked on the working drawings for this steel. And, as excavation gets under way, the steel company begins to ship carefully marked girders from the plant to the scene of construction. The steel is shipped either by water or by freight train.

In the picture to the right you see a contract drawing for a typical subway section of two-track width. The steel girders marked "A" are the main parts of the subway structure. Usually they are painted a bright red at the plant in order to keep the girder from rusting. Each one is carefully marked with a system of letters and numbers which indicate to the steel erectors on the job just where each particular girder is to go in the structure.



CROSS SECTION OF A TYPICAL SUBWAY STRUCTURE

This one is only two tracks wide. Many are three or four tracks in width, but the method of construction in those sections are the same as here. Here are the interpretations of the cross-section:

The big "A's" on both sides, the top, and the middle of the drawing indicate the sturdy steel girders which make up the main part of the structure.

The three "B's" at the bottom show where the extra-thick concrete is poured, in which the steel girders are set; while—

The two sections marked "C" are the thinner layers of concrete which form the bottom of the structure on which the tracks are laid later.

The two "D's," one on each side of the drawing, mark the duct banks referred to on page 142—those duct banks which are used for subway wires and cables alone, and not for any of the subsurface structures.

On the top of the drawing you will note the phrase "3 ply W.P." This refers to the layers of waterproofing described on page 140.

You will recall, of course, that the concrete walls of the structure are poured in between the great steel girders, which are spaced about five feet apart. The way the subway looks both with and without this concrete wall is shown in the bottom picture on page 139.

The steel is brought to the scene of construction on huge trucks, and each member is unloaded, one at a time, by the contractor's derrick and piled neatly by until it is called for in the cut down below. The contractor always arranges with the steel plant not to have too many girders shipped at once, so that just enough steel comes in to keep a few sections in advance of actual construction in the subway pit.

CONCRETE

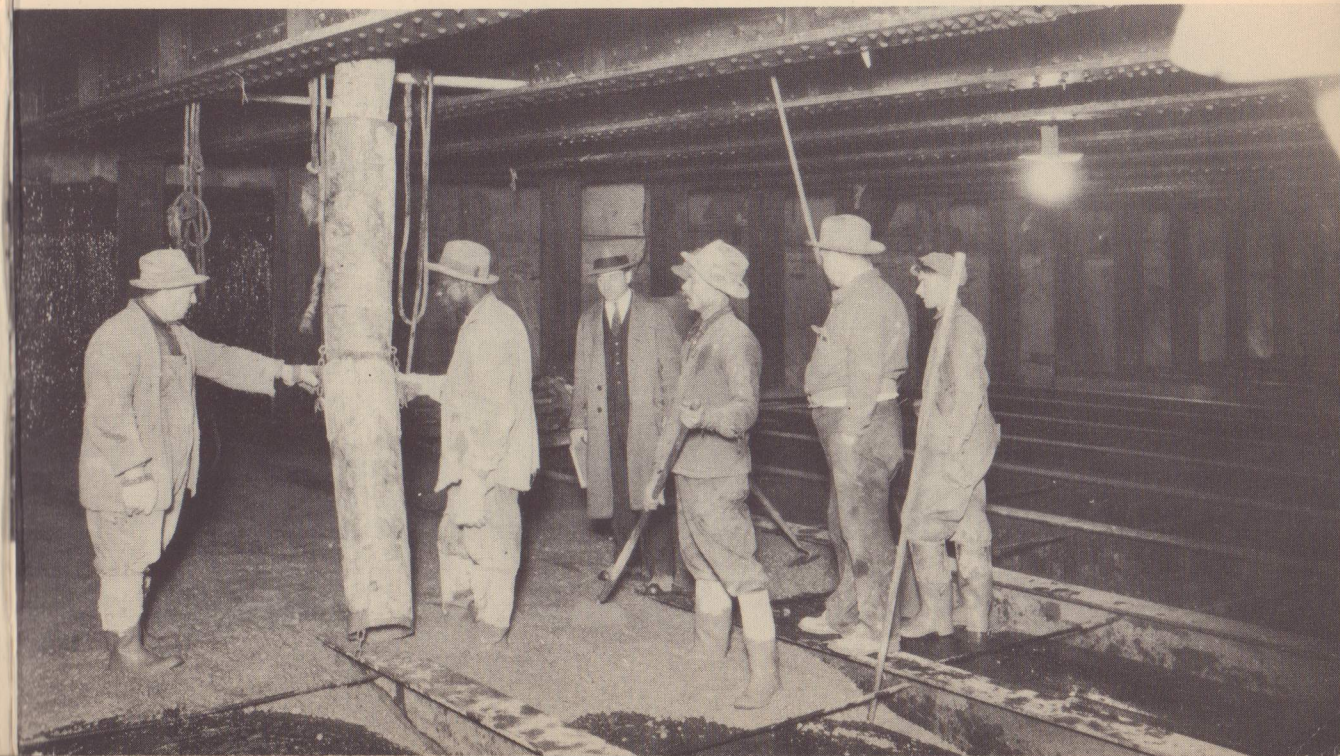
Meanwhile the contractor, supervised and aided by the Board's engineers, has been laying the foot-thick concrete floor of the subway and the much thicker concrete ridges down each side of a track space where the steel girders are to be set up.

In New York City most concrete work is done by a remarkable new method. No concrete is mixed on the job. Far away, in cement-mixing plants, batches of concrete made according to the formula which the Board specified, are poured into huge concrete mixers or hoppers. These concrete mixers are great revolving cylinders, securely fastened to powerful motor trucks. A truck starts off across town to the subway job with the full cylinder busily revolving as the truck travels, mixing its batch of concrete thoroughly on the trip. When it arrives at the scene of the subway work, it backs up to a place where the decking has been removed for a couple of feet. A large funnel rests there, from which an eight- or ten-inch tin pipe extends down through the excavation to the wooden molds which are waiting for their load of concrete.

Here the driver of the truck tips the loaded cylinder up directly over the funnel and lets his load of mixed sand, cement, water and crushed rock slide down through the funnel to the bottom of the sub-



Here is the way concrete arrives at a modern subway construction job. No more do you find unsightly piles of sand, cement and crushed rock all along the street, waiting to be mixed into concrete. Below is the other end of the funnel into which the concrete is poured. This is the end it comes out of. (Top photo, courtesy of Spencer, White and Prentis.)



way. The area to be filled with concrete is usually covered with a strong network of twisted steel rods which serve to reinforce the concrete after it is poured, making it twice as strong as it would be otherwise.

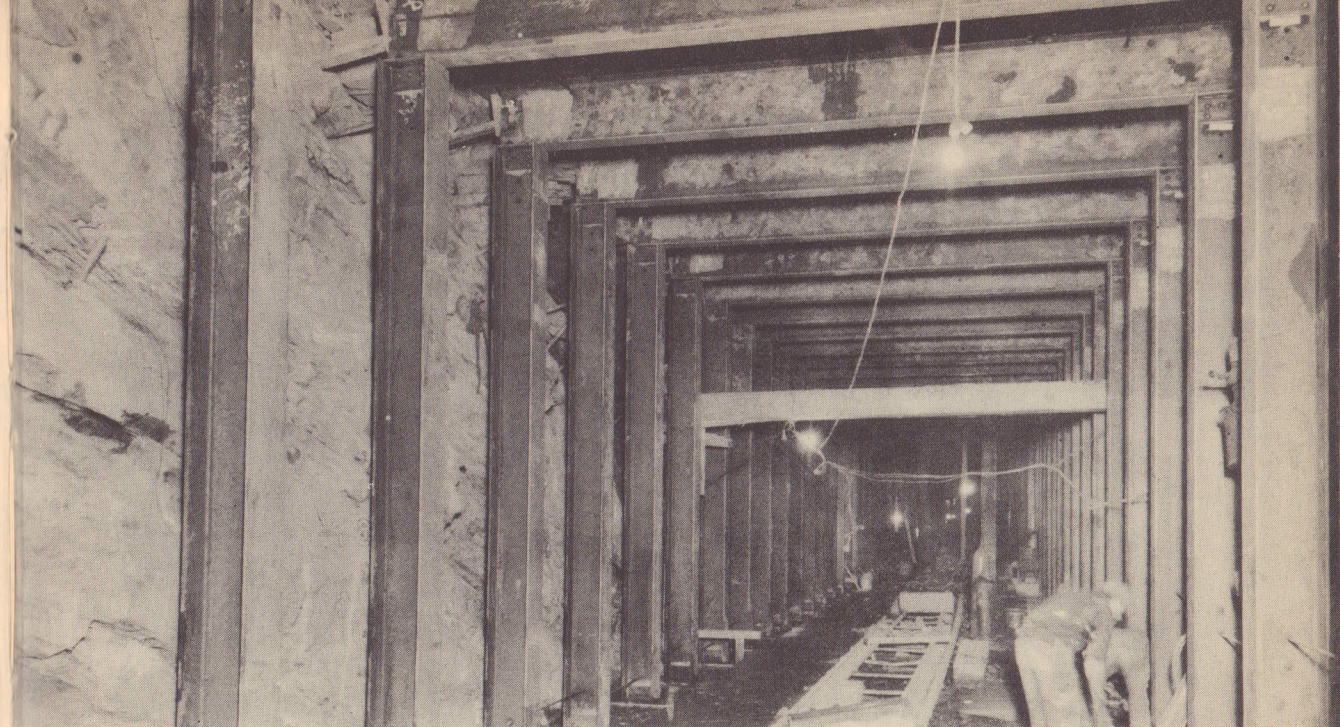
As soon as he has emptied the cylinder, the truck driver leaves for another load. Then another loaded truck drives up and dumps its concrete. Thus the floor of the subway is laid, provisions being made in the molds, of course, to allow space for drainage systems. The raised portions of the floor (marked "B" on the section drawing) where the steel is to be erected are also poured at this time.

STEEL CONSTRUCTION

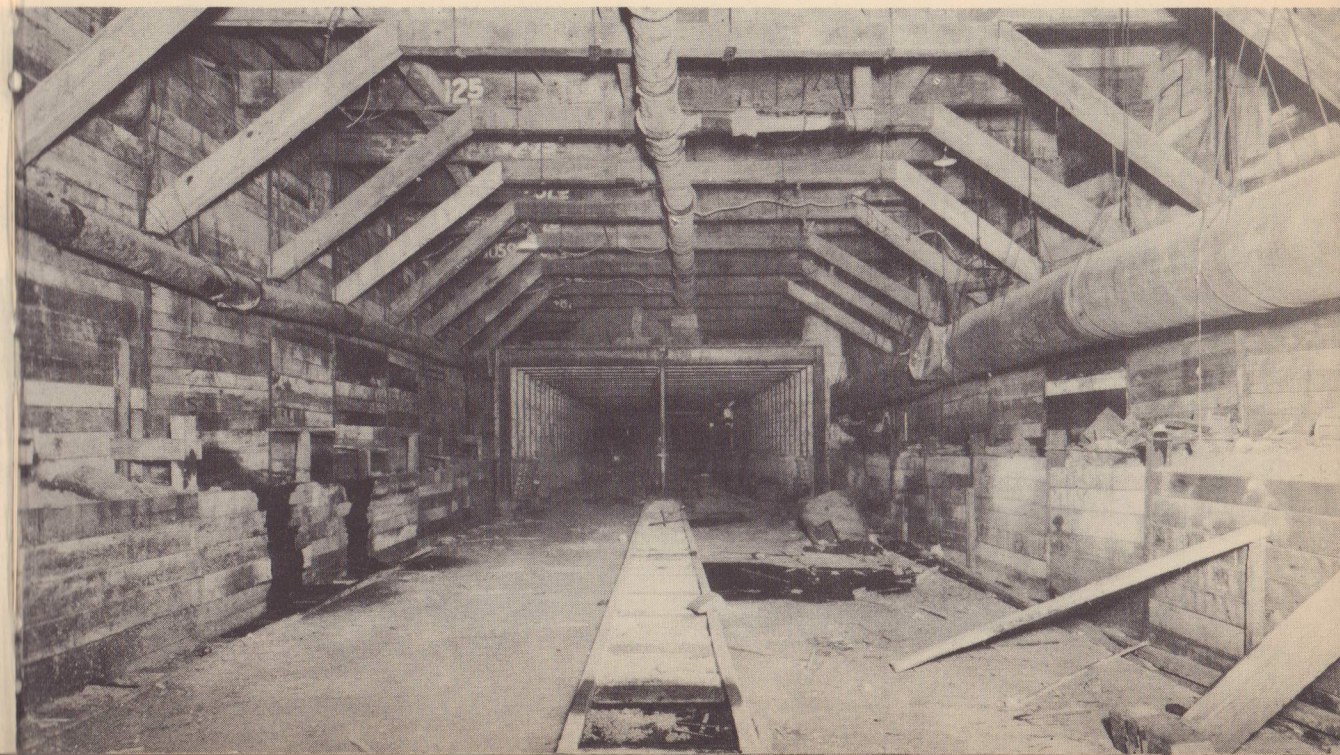
After the concrete has thoroughly *set*, dried out and become hard, the erection of the steel begins. The various girders and cross-beams are let down into the excavation by the crane overhead, and are then set into place as indicated in the drawings.

And now come the riveters, setting up a terrific noise. The rivet heater prepares his coke fire in a little portable furnace which he wheels up to the scene of action, buries the rivets deep in the heart of hot coals, and lets them come to a white heat. Then he pulls one of them out with long pincers and tosses it to the riveter's helper, who catches it in a pail, dextrously lifts it out with his pincers, and places it in the rivet hole. At this point the riveter, with his compressed-air riveting gun, hammers the red-hot rivet home with a clatter that can be heard blocks away.

A large number of rivets are used in every beam and in every girder and each rivet must be hammered in with the noisy riveting machine.



Two types of steel construction. Above—Steel being erected directly against the solid rock sides of a single-track tunnel. Below—The excavation has been in dirt, and for a two-track width subway. Note how much space there is at the sides and at the top in this type of cut-and-cover subway work.





A maze of steel. At this point, there are three levels which you can count in the steel frame. The bottom two will carry tracks; and the third will be the mezzanine of a station.



Structural steel going into place in an open cut. Note that concrete is also being poured in this picture. Below—Further steps in construction. You can see in the foreground (left) the naked steel girders—and in the background, the same row of girders encased in concrete to form the collision wall.

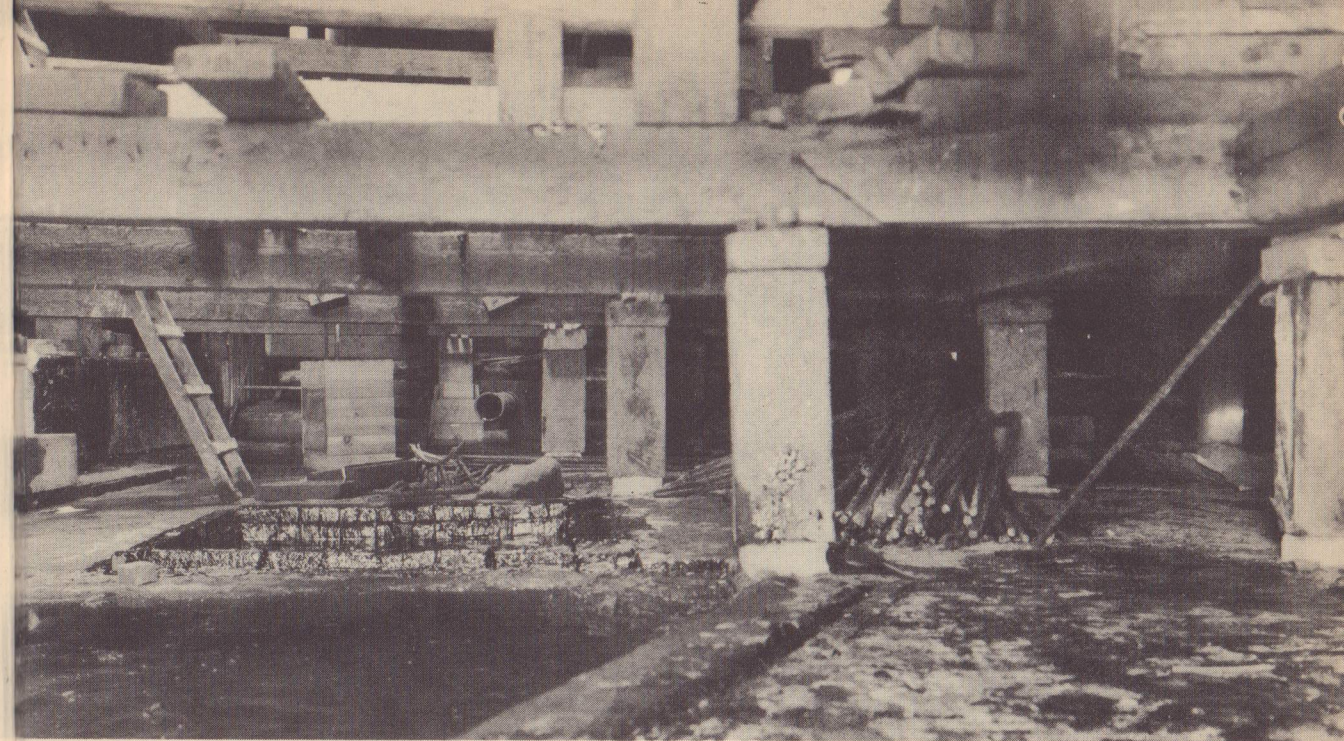


First the crews rivet the vertical supports into place and then the cross-beams overhead. In a two-track section, a typical section consists of three vertical girders—one at each side and one in the middle—and one or perhaps two cross-beams at the top. Thus the naked structure of the subway is formed and slowly grows into place inside the excavation.

Behind the riveters come the masons who pour concrete against curved wooden forms in between each section of the steel. Usually in New York subways the steel uprights are placed five feet apart, and the areas between each section are first securely banked up by wooden molds with concave outward surfaces. Then concrete is poured into the molds and allowed to set and dry before the molds are removed. The steel girders between the tracks may be left naked, with no concrete between them; though in most modern subways there is a thick wall of concrete between center girders at certain locations. This center concrete wall is called a *collision wall*—for the reason that it will shunt off a subway car that leaves the rails and glides into the wall, thus preventing it from crashing onto the next track.

WATERPROOFING

If a section of the subway is below ground-water level and there is danger of water seeping through into the structure, the concrete must be strongly waterproofed. Two or three layers of heavy cotton cloth thickly impregnated with pitch-black asphalt are laid over the whole outside of the concrete surface. If this is done correctly, practically no water will seep through the walls.



Here the waterproofing is shown. The photo above shows the brick-in-mastic being laid; and that below shows fabric waterproofing in place both on the floor and the walls of the subway.



The ceiling, or roof, of the subway is made much in the same manner as has been described above. Wooden forms are fastened up in between each cross-beam, and concrete is poured against the forms till a thick, solid layer of material is formed. As soon as it has set, waterproofing is put on the outside of it and the job is done.

If the roof of the subway is below water level, a specially strong method of waterproofing is used which consists of a layer of bricks laid in a thick bed of *mastic*—a tar compound absolutely impervious to water.

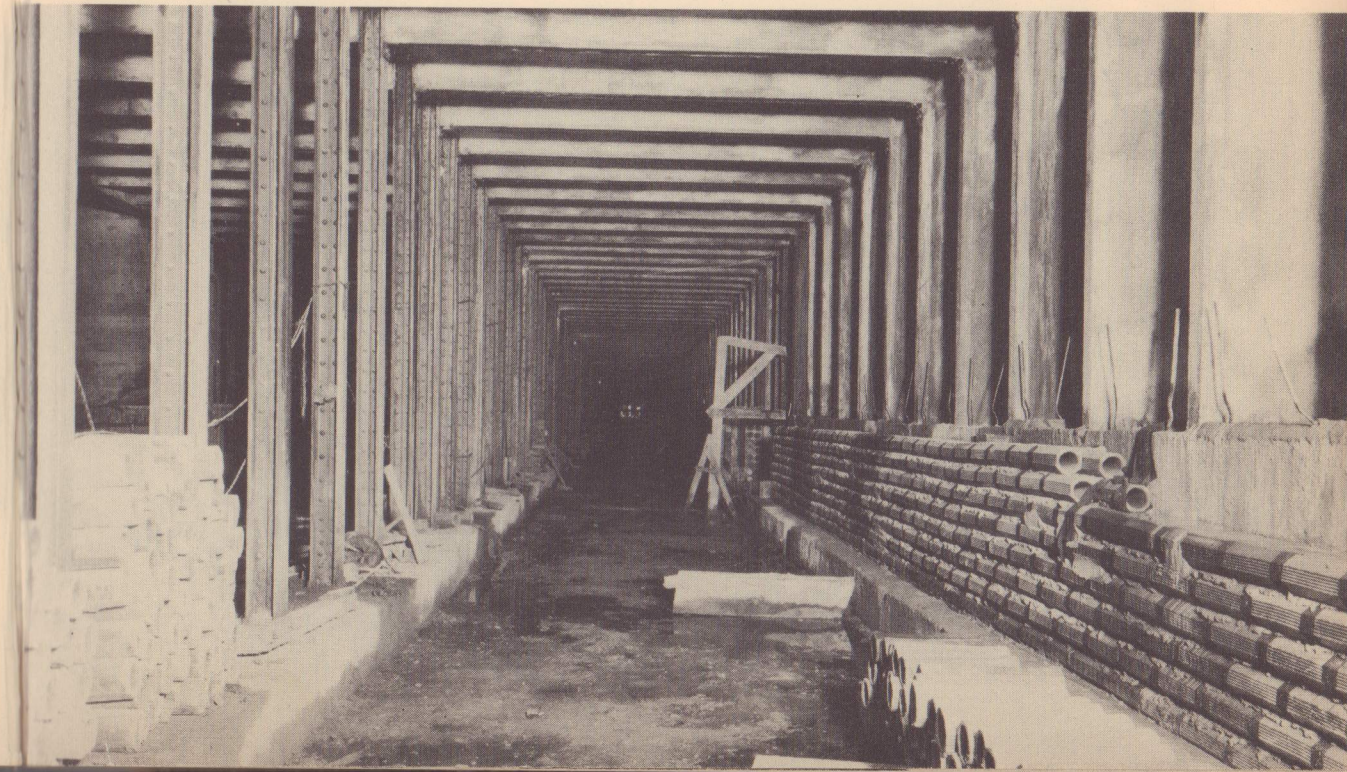
DUCT BANKS

Even at this point there are still many tasks that must be performed. Sometimes special drainage systems must be installed. And always, in every subway job, the contractor must install banks of ducts on one or both sides of the structure.

These banks of ducts (marked "D" on the typical section, p. 133) are made up of sections of hollow-tile piping, which are accurately laid to form a continuous series of empty pipes alongside the subway tracks through the whole length of the route. They will be used later to carry all the various complicated wiring systems needed to run the automatic signal equipment and track switching equipment which makes modern subway travel so safe. They will carry, too, the regular light wiring, subway telephone wires, etc. But none of the cables which make up the mass of subsurface structures lying above the subway structure will run through these ducts, for these ducts are built for subway use only.



An enormous concrete sewer being built according to specifications of the Sewer Department of the City, by the construction contractor. Sometimes they come even larger! Below—Concreted steel (right), naked steel (left) and the duct banks being laid along the side of the structure.

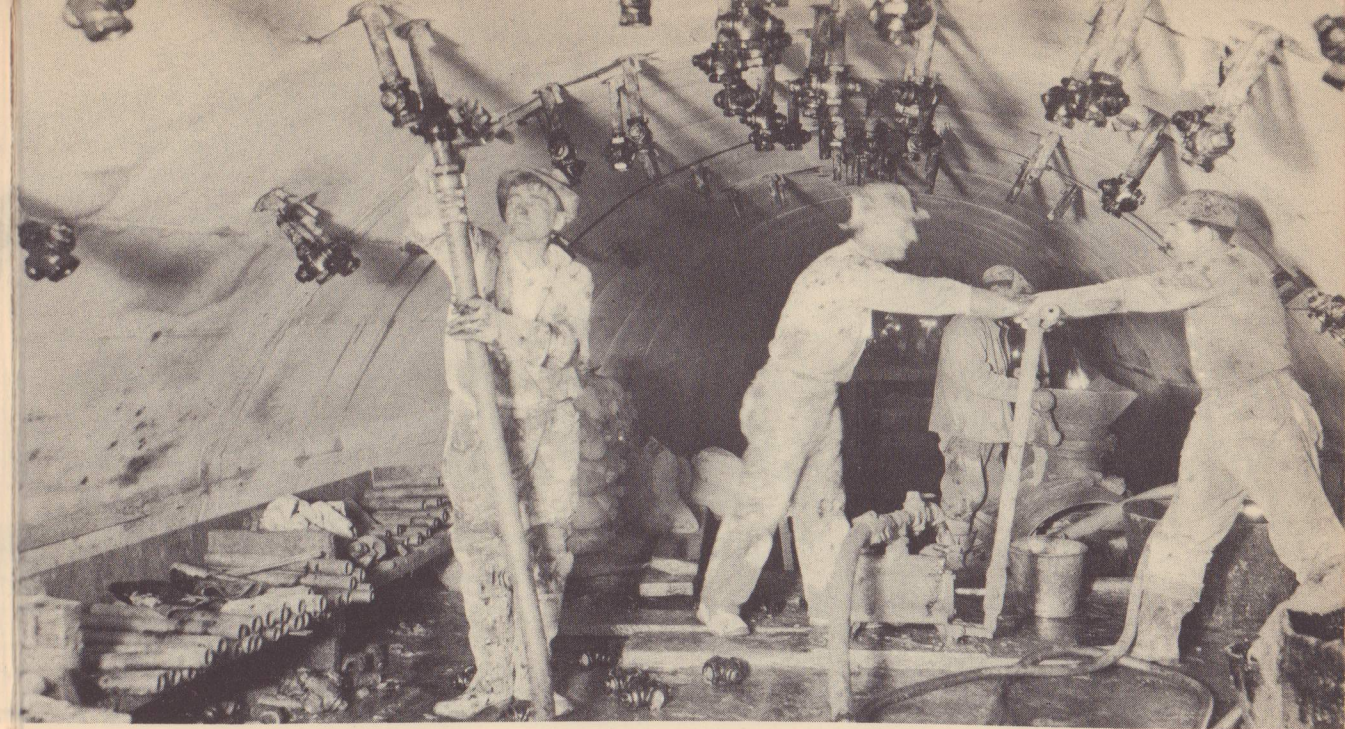


CONSTRUCTION IN ROCK TUNNELS

Much the same kind of construction methods are used in rock tunnels, if the rock is firm and hard. However, in some cases the contractor has to put in a circular tunnel made out of steel or concrete. In most tunnel jobs the specifications call for cast iron tubes of the same type put up in shield work. Again, in some rock tunnels the construction is in the form of high arches. The side walls may be of regular steel girders, but because of the height of the tunnel the roof is first prepared with specially designed curved steel girders and then smoothly finished with concrete arches. The kind of construction used depends entirely on the specifications required by the engineers of the Board of Transportation, who know in advance the nature of the strains, stresses, and weights the structure is going to have to bear.

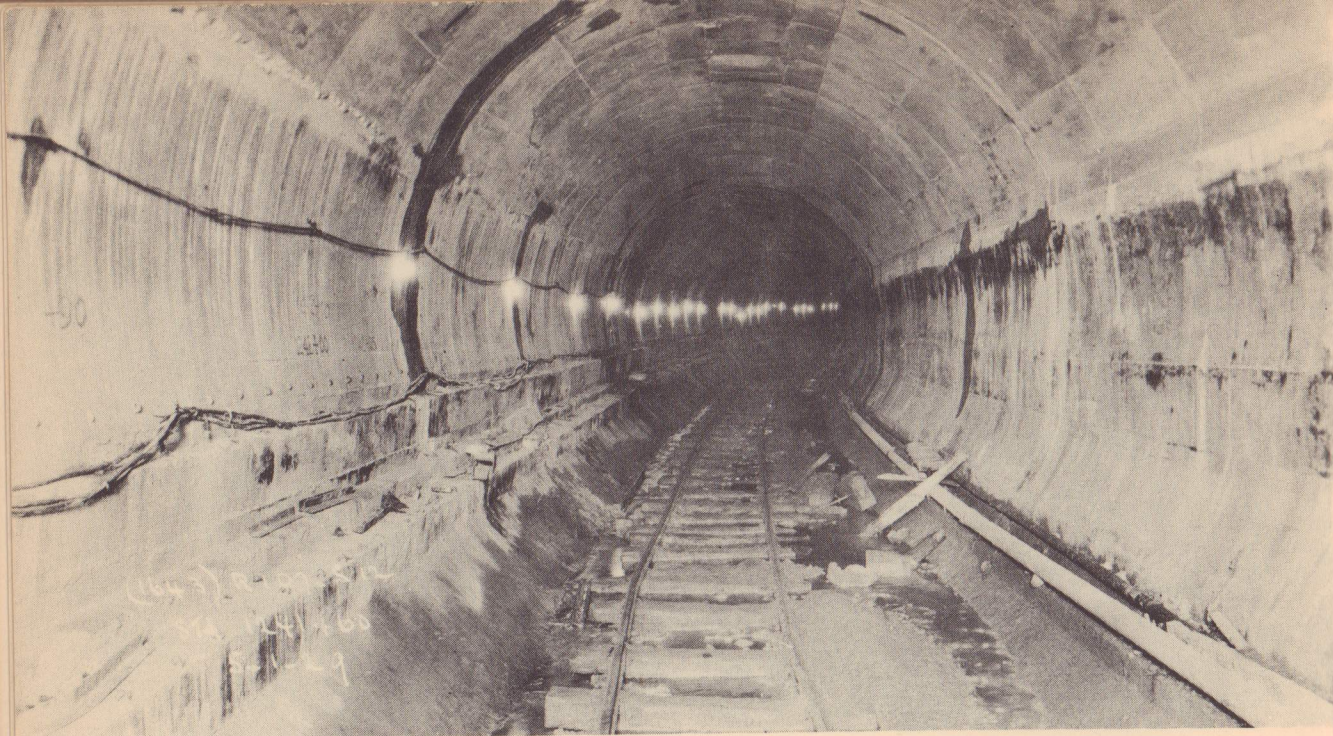
In a cast iron tunnel, laid with the aid of a shield, the iron rings in the old days used to be left naked and unconcreted. But all modern subway tunnels allow for a thick layer of special waterproofed concrete lining to be laid right up against the cast iron tunnel rings.

However, before this is done—and usually while the shield-driven tunnel is boring through the broken rock or mud—another process takes place which makes the tunnel solid *outside*. This is called *grouting*. You see, after the tunnel rings are in place there remains outside of them quite a bit of space which had to be excavated in order to get the shield, which is slightly larger than the tunnel itself, through the excavation. By grouting, these outside spaces are filled up with finely broken, gravel-like stone and with a thin semi-liquid cement. The way it is done is this: Workmen push pipes out through the grout-holes, which were made in each tunnel segment when it was cast.



Grouting. The two men at the right are working a hand-pump which forces the grout out into the spaces beyond the tunnel, through the hose which is attached to a grout plug being operated by the third man at the left. Below, a crew of subway workers posing for their picture after having practically finished their tremendous job of construction.





A finished tunnel, before putting in tracks or any equipment. It is solidly concreted, and the spaces outside of it thoroughly grouted. Below is a place where a section of circular tunnel joins with a section of regular subway structure. The tunnel part is not completely concreted yet, but the other part is ready for the track and signal installers.



Through these pipes they force under air pressure this grout of gravel and thin cement into the outside voids and spaces. This fills everything up tightly and prevents the material outside from slipping or settling against the tunnel sections and damaging them.

Grouting is not usually done in cut-and-cover work. Here earth or gravel is firmly tamped down between the subway wall and the outer line of the excavation so that there will be no danger of slides or slips.

CLEAR-AWAY JOBS

As the subway structure proceeds—whether in cut-and-cover, rock tunnel or shield tunnel excavation—the temporary shoring of the side walls is removed and the weight which this shoring was holding is transferred to the outer walls of the subway structure proper. This can of course only be done as the building proceeds; every time a new length of the subway structure is put in, the temporary shoring must be removed to make way for it. But this shoring cannot be removed beforehand, for if that was done, the danger of accidents from slides and collapses would become as great as if there had never been any protective sheet piling and cross-beams.

And now, if you go into the structure itself, it begins to look familiar. There are no tracks yet, of course, nor are there any trains nor any signal equipment. Things are rather upset and dirty. There still may be lots of water running down the center of the structure. At the places where there are to be stations, the platforms are just masses of naked and ugly-looking concrete, and the walls have no tile on them yet. Nevertheless, it is not hard to imagine that in a few months trains really will be running here underneath the teeming city!

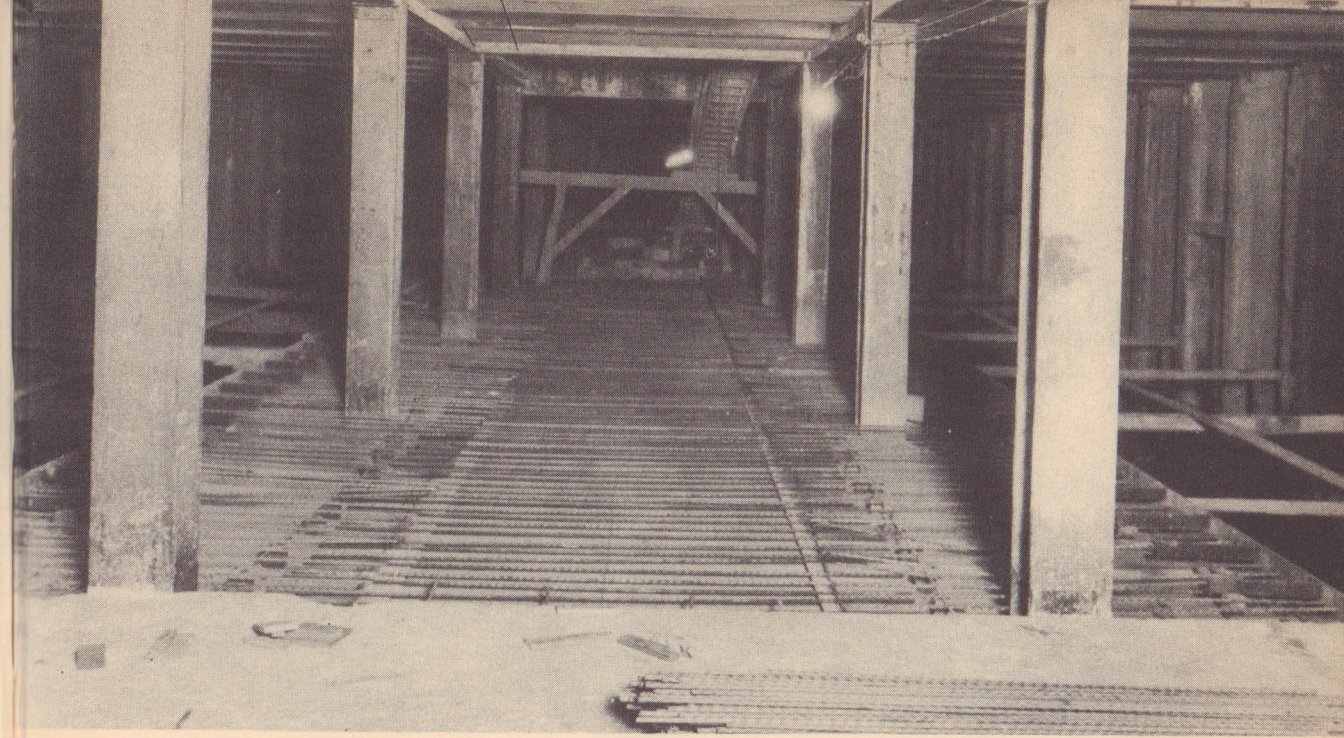
In the meantime, however, much remains to be done. The excavation contractor himself still has months of work to do, putting back into place all the things he had to disturb while building the subway.

First he must start *backfilling* the subway excavation. This means that he must find earth, gravel and clean small cinders in great quantities to fill in the spaces between the side walls of the structure and the outside wall of the excavation, and also the space of from six to ten feet between the top of the structure and the street decking overhead. All this material must be strongly tamped down so that it will not settle too much.

At the same time he must relocate all the great mass of subsurface structures at suitable depths in the backfill. He must lay new concrete banks of hollow tile ducts for all wiring; install brand-new concrete sewers and new piping for the gas mains, and so on. Once again he is directed in this by the owners of the various public utility and municipal systems of pipes and wires.

He must place gratings at stated intervals in the new sidewalks to allow for ventilation in the subway. He must build permanent sumps for subway drainage wherever the Board of Transportation engineers indicate them. And finally he must remove the decking overhead and lay new pavement, leaving everything as he found it two and a half years before when he first started the job.

Of course, the contractor who has had a tunnel job does not have to worry about all these surface things, as does the contractor for a cut-and-cover section. But the tunnel builder has an especially complicated job of drainage arrangements, such as sumps, pumps, etc., to do; for much more water is to be found in deep tunnels than in construction nearer the surface.



The construction contractor's last job on station platforms is putting in the reinforcing steel rods, and then covering them with a layer of concrete. Below—Backfilling under way. Pretty soon traffic will be running on the backfilled part of the road, while the other half, where it now is going, will be getting its load of earth and rocks.



Block by block the subway structure is finished. The contractor's men clean away the debris and test the walls and floors. Gradually the confusion of construction equipment—the cranes, the trucks and piles of materials—disappear from the roadway overhead. The life of the resident and storekeeper on the street returns to normal.

And down in the subway itself everything is ready for a new set of contractors and engineers who have the final installation work to do—the operating equipment.

CHAPTER EIGHT

INSTALLATION OF TRACK

ONE would think that the laying of track, the installation of signal equipment, the application of station finish, and the completing of numerous minor details would be matters requiring a relatively short amount of time. But surprisingly enough the designing of track and signal equipment are among the lengthiest, most scientific and most difficult jobs in all subway work.

TRACKS

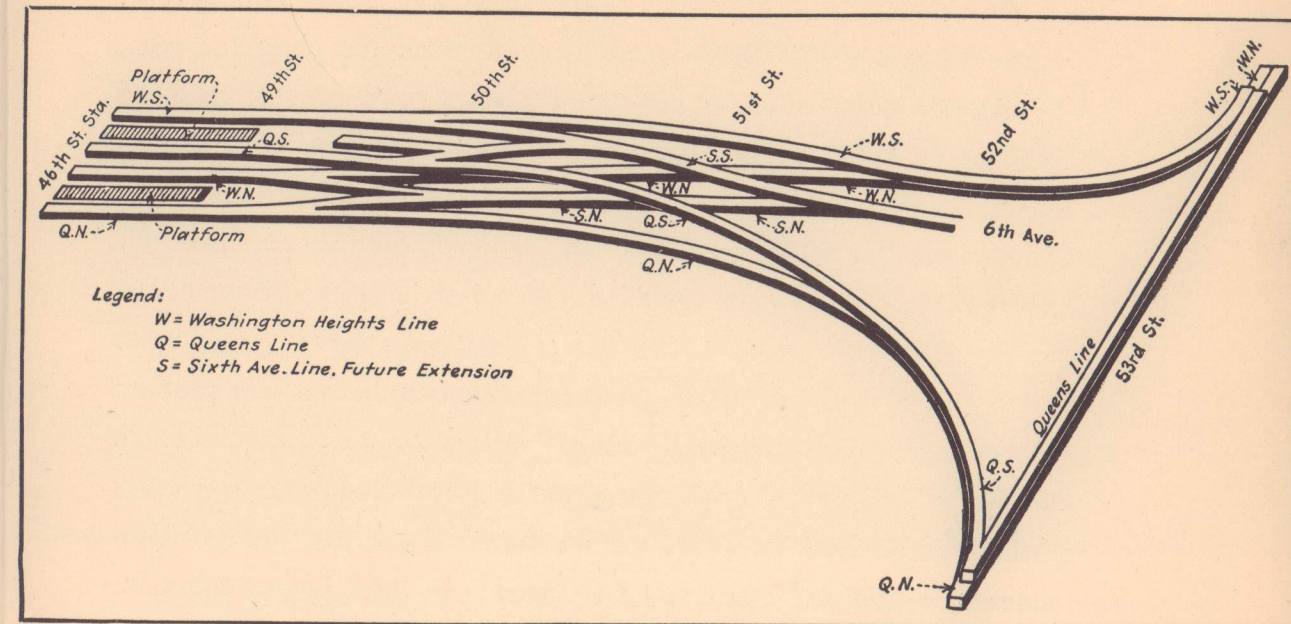
There are hundreds of complicated problems involved in the designing of track, and *they all must be dealt with approximately at the same time that the structure itself is being planned!* In other words, as soon as the actual line and grade of the new subway is known, before the Board of Transportation engineers have even commenced to work on their contract drawings, the designers in the track division of the Board start planning the track layout. The reason for this is that it frequently happens that necessities of track design may materially alter the route of the subway. The construction design division of the Board must know what the track layout is going to involve, before they can design a structure that will make this track layout possible.

Track plans are thus prepared after many months of work in close co-operation with the construction division. And the plans for tracks are always designed for sections of the subway running at least five miles in length, more if possible. Indeed, when possible, the most important elements in track design—grades and curves—are plotted out for a whole subway system, though construction, and even the construction drawings themselves, may not be wholly completed for years to come.

The reason for this is that track engineers could not just plot out the tracks for a half-mile of structure, leaving the rest for another designing crew, because so many intricate problems involving the whole length of the route must be considered.

These include, first and foremost, what sort of grades are going to have to be coped with? And how many curves, and how sharp will each curve be? Grades are rarely allowed to be greater than three per cent—only once in a great while is it permitted that they reach four per cent on downhill grades. A grade of three per cent means that the tracks go uphill or downhill at the rate of a three-foot rise or fall in each horizontal 100 feet of distance traveled. To avoid greater grades than that, changes in subway design are sometimes necessary. The same goes for curves, which only in exceptional cases are permitted to be sharper than a 500-foot radius. Even that is an extremely sharp curve; the best radius for modern high-speed subway trains is one on a radius of 2,500 feet.

Another point which must be considered early in track and structure design is how many *cross-overs* there should be. A cross-over is a switching arrangement between sets of tracks, so that trains traveling on one track can be switched over to another track when necessary.



A drawing which shows one of the really complicated pieces of track design which the subway track engineers had to figure out. There are six separate tracks, each of which has to cross the other in a marvelous maze of twisting steel. Designs of this sort are technically known as "flexing" of tracks. (Courtesy of Engineering News Record.)

Cross-overs call for a widening of the subway structure at that point—and changes in structural design must be made accordingly.

Again the question arises, how many *storage tracks* must be allowed for. Storage tracks are sections of track laid in addition to the two or four tracks which make up the local and express systems on an average subway. They are used to hold trains of cars in readiness for service at rush hours or in special emergencies.

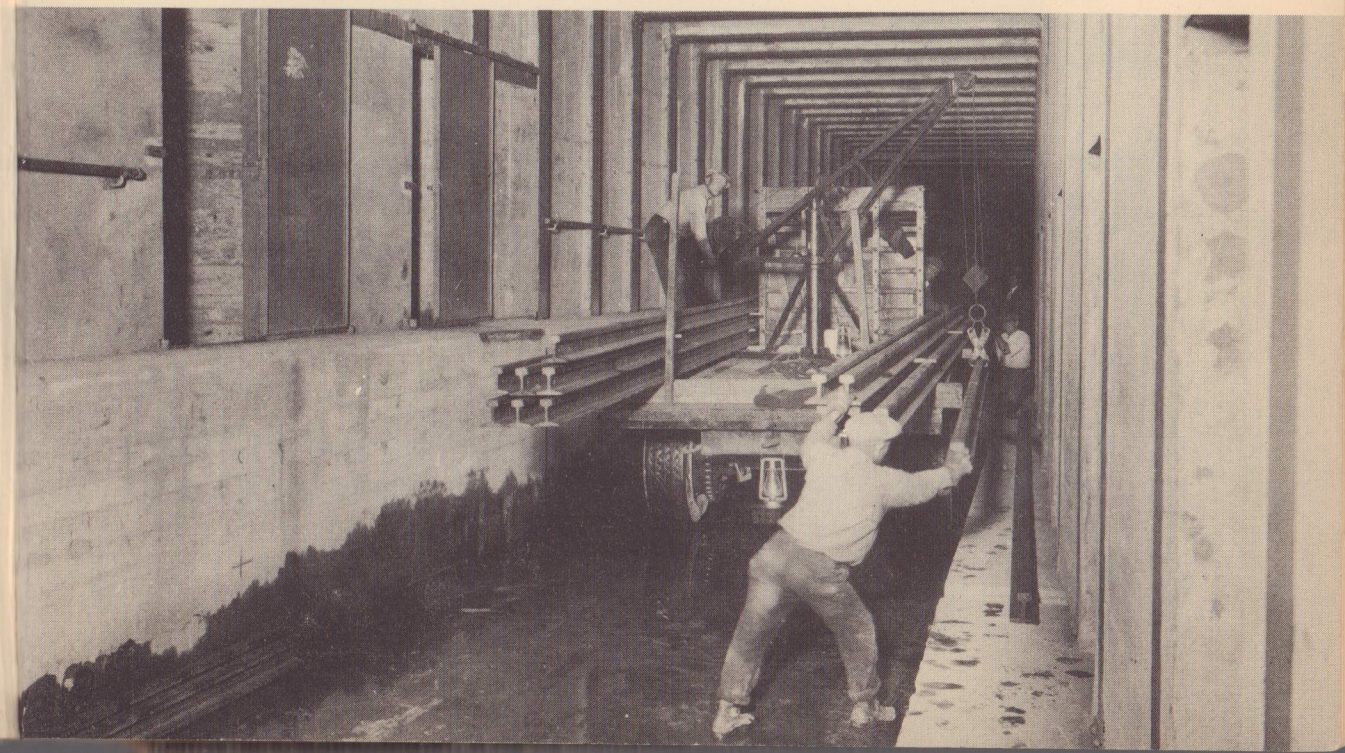
All of these points, and many others, must be thoroughly agreed upon by track and structural design departments long before construction or even excavation begins. As soon as the designers in the track division of the Board of Transportation have completed the enormously complicated drawings for the track layout, the work of fabricating the rails and other materials needed in track laying is begun. Steel plants and other manufacturers submit bids for the manufacture of this equipment just as the construction contractors did for the excavating and building jobs. The lowest bidder among the manufacturers gets to work making steel rails, according to the designs. The rails used in all the city subways are thirty-three feet long, and weigh 100 pounds per foot. In places where much wear is expected, as on sharp curves and at switch points, the rails must contain a certain percentage of manganese, a hardening alloy.

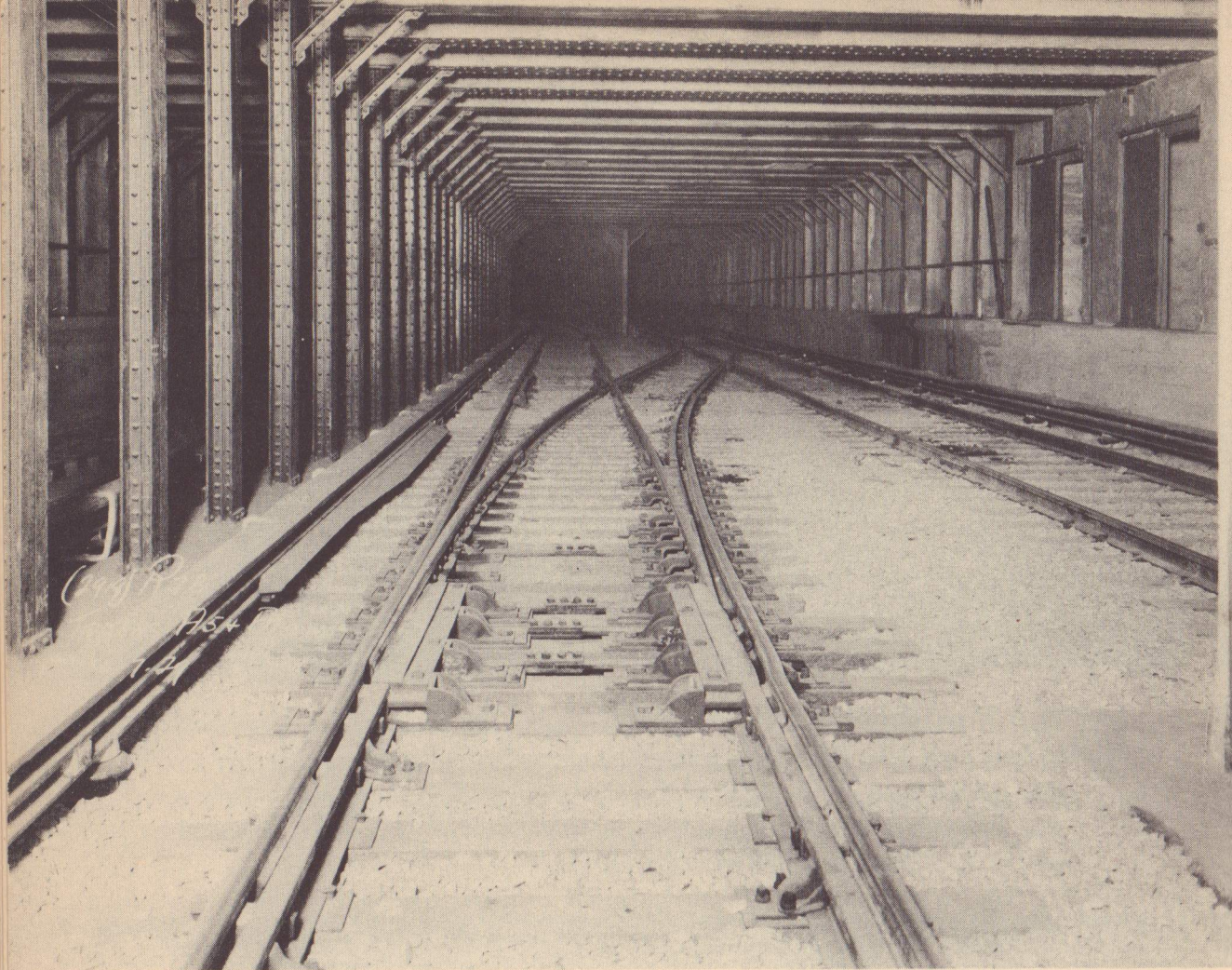
Other manufacturers, who bid separately for the various items mentioned, now get to work making bolts, nuts and washers, spikes, tie plates (used to fasten the rails to the ties), special heavily creosoted wooden ties, and many other technical types of equipment.

The absolute accuracy with which the heavy and cumbersome steel rails are made is really a marvel of engineering. Especially if the rails must curve to the right or to the left, or up or down as when



(632) R105. Truck hauling
Piles of track stored and waiting to be hauled down into the new subway and to be put in place. The crane lifts one rail at a time and places it on the waiting truck at the right of the picture. The same truck, in the picture below, is shown down in the subway with its load of rails being taken off and placed along the side of the structure.





Sample of ballasted track (see page 158), at cross-overs and switch areas. The mechanisms in the foreground of the picture are the switch housings, which protect the tip of the switch and keep trains from running off the tracks.

there is a beginning or an end of a grade—or even *both* to the right or left *and* up or down, as sometimes happens—they are carefully bent in enormous and highly accurate bending machines in the plant, so that they agree with the exact specifications made in the track drawings.

Switches and all their numerous parts are individually designed and made. The *switch* part, consisting of the movable piece of track which can be pushed from one side to another so that a train coming along will either go down straight ahead, or, if the switch is turned, go over across the switch to the track that it connects with, is strongly protected (*housed* is the term used) so as to keep the wheels of the speeding trains from jumping the track at that point. The *frog* part, which is the section of the switch where the tracks cross each other, is carefully designed and protected with long guard rails. All the points of greatest wear are made out of a manganese-alloy steel.

Further, in addition to this complicated system of track with its switches, curves, grades and the like, the lighter rails used for the *third-rail system* are manufactured according to the designs of the track division. The third rail is that which carries the electric power which makes the trains go.

TRACK ASSEMBLY

Then, as the construction contractors move out of the completed subway structure, the work of installing the tracks, with their specially prepared bases, their ties, and all the other needed equipment, begins. Installation is done by still another contractor, who has special knowledge of this kind of work. There are two chief types of track assembly

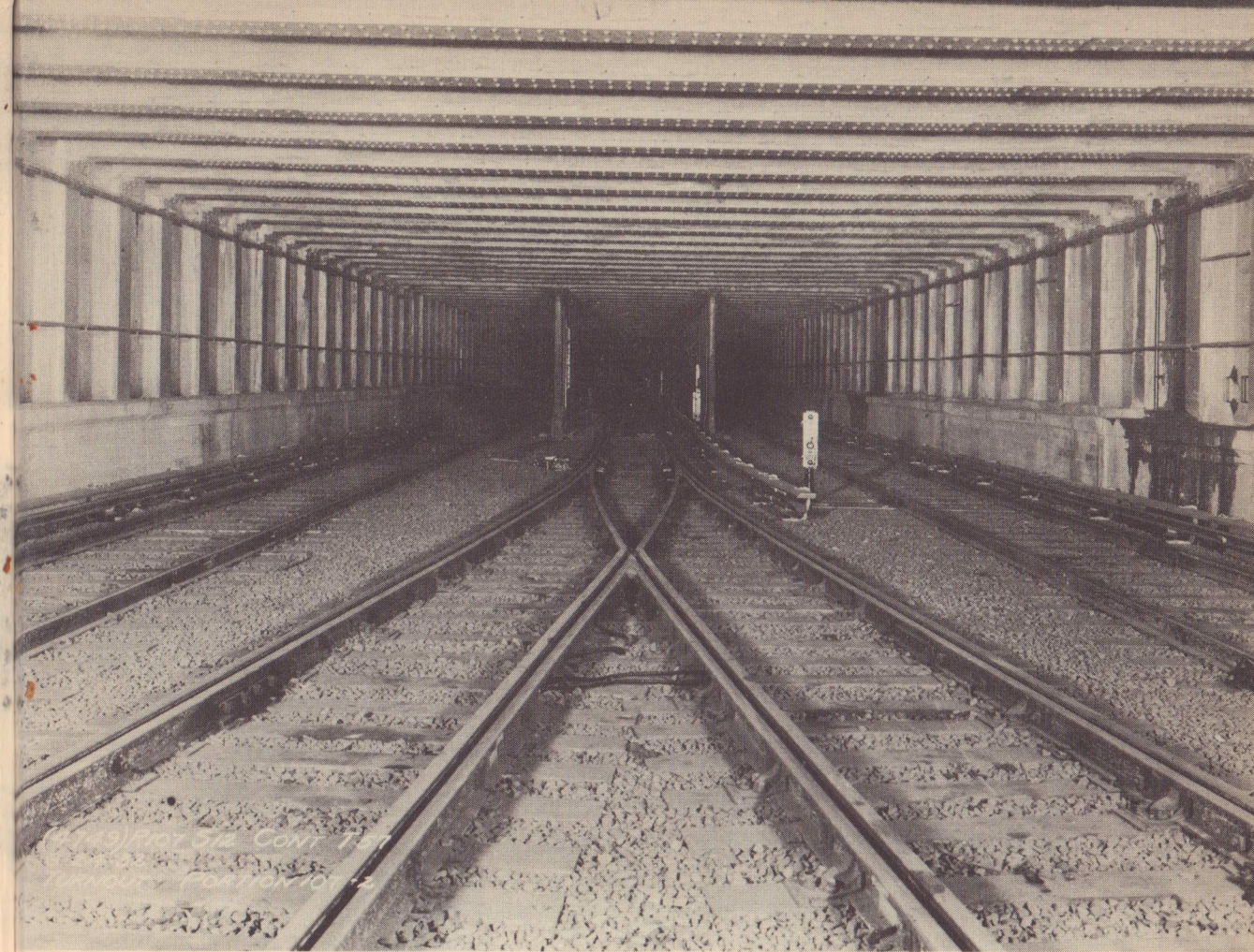
in modern subways; the oldest, and the one now less and less used, is the *ballasted track*.

1. BALLASTED TRACK

A ballasted track is just like the layout you see on any steam railroad. In the subway they lay as many inches of clean rock ballast as there is room for, say seven inches or more. This rock is composed of broken pieces of stone about the size of a small fist. The ballast is laid directly on top of the concrete floor, or *invert*, as it is called, which the construction contractor had put down. This ballast is then tamped down as firmly as possible, and heavy creosote-soaked ties, eight by eight inches thick and several feet long, are placed across the ballast, one every two feet or so, and more ballast is tamped down between them until they are firmly held in place by the rock. The rails are then laid on the ties, carefully spaced for equal width apart and carefully leveled for equal height, and are securely fastened with spikes and tie plates to each tie.

In ballasted track, drainage must be led through the rock ballast to special drain systems already prepared in the concrete invert. A great deal of expensive maintenance work must be kept up in the ballasted track system. The ballast must be constantly tamped down; the rails must be checked for shifts in width apart and in levels; and every ten or twelve years the ballast must be completely renewed. This is an expensive and difficult procedure, especially when trains must be kept running all the time.

Because of these disadvantages, ballasted track is now used only at switch points and cross-overs in most modern subways.



A picture of a "turn-out," or special type of switch. The place in the exact center of the picture where the tracks cross each other is the "frog." Note that ballasted track is used here also.

2. TYPE II TRACK

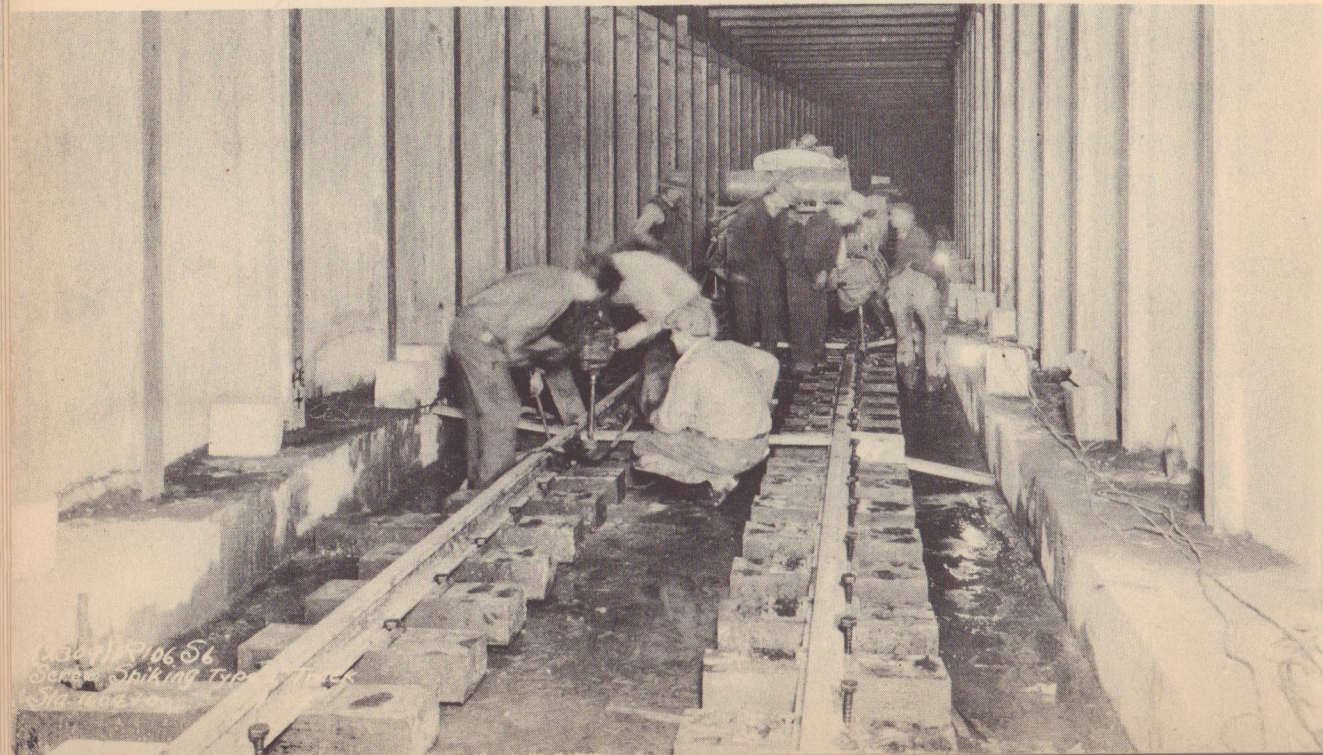
The type of track assembly most used in modern subways, known to subway engineers as *Type II*, is a very different thing.

In this type of track a much shorter tie is used. These short ties are six-by-ten-inch blocks of the finest pine wood, heavily creosoted in order to forestall rot. Creosote is a tar substance that makes the ties fairly impervious to water. The ties are so short—only two and a half feet long—that they run crosswise under only one rail each, instead of all the way across both rails. Thus between each set of short ties there is left a space about two and a half feet wide, with no ties in it at all.

After the rails have been laid along the tunnel, the short ties are jacked under them and the rails are fastened to the ties with special screw spikes and tie plates. Then, as soon as the rail laying has been approved, the system of ties and rails must be made firm and unmovable. The way they do it is this: first, across the inside ends of each pair of ties they fasten a series of boards, which serve to protect the trough between the two sets of ties from the concrete which is about to be poured. As soon as this board protection is in place, specially prepared concrete is brought into the structure and is carefully poured in between the short ties, clear out to the outer walls of the subway structure. The concrete is allowed to flow in until it is only an inch or so below the top of the ties. Then it is permitted to harden, and the result is a firm and immovable combination of track, track ties and concrete, with a trough between the left and right tracks which is itself a very useful thing in the modern subway.

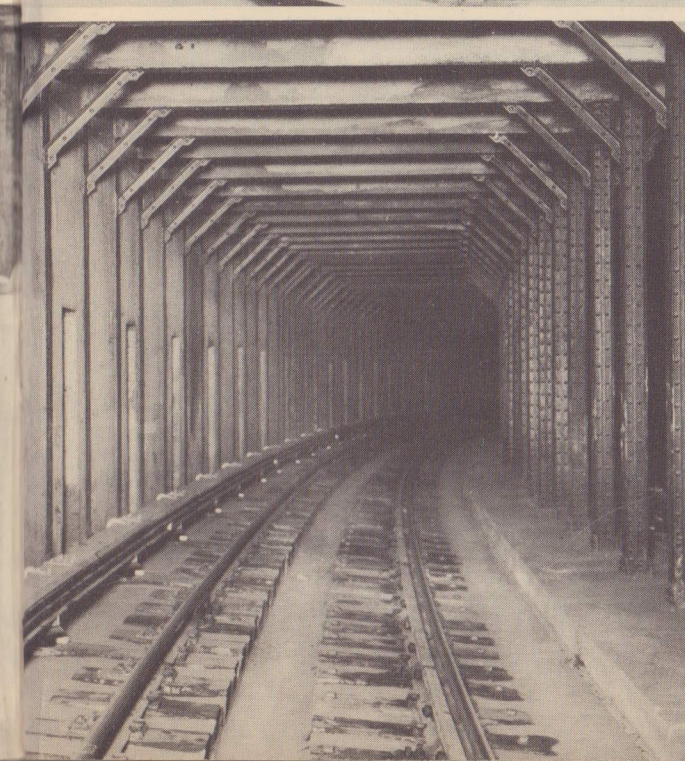
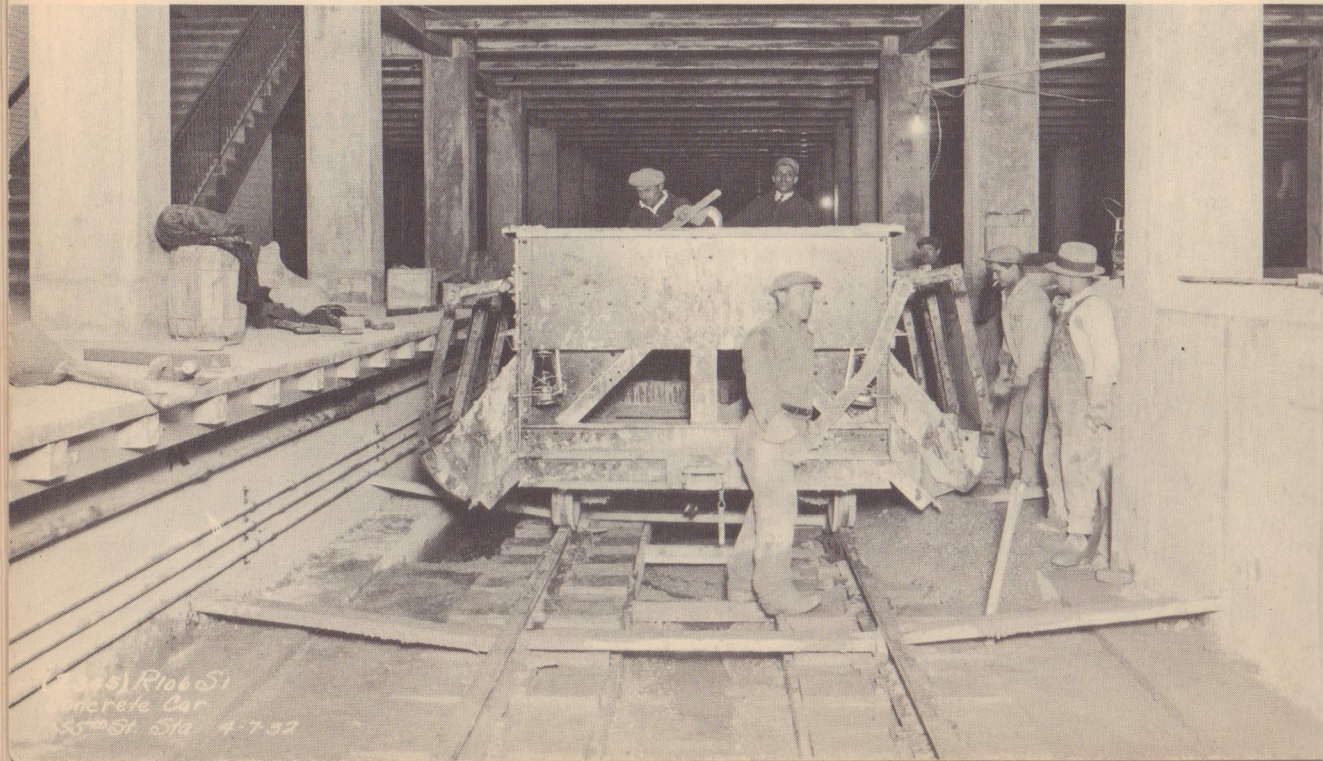


The short ties, always used with type II track, being inserted under the rails. The rails have been loosely bolted together along the length of the subway, and the ties are put in place by means of a hand jack, which lifts the rail so that the tie can be pushed under it. Below—The ties are all in place, and the rails are being spiked to them, with power drivers. Note the air compressor machine. It furnishes the power to the spike drivers.





Concrete, mixed on the surface—frequently, but not always, in plants far away from the scene of construction, just as it was when the subway structure itself was being built—is dumped into the space between each tie and between the ties and the subway walls. Below—Another type of concrete cart.



While the concrete is still setting, engineers run this peculiar machine through the subway, measuring distances from top and walls, to make sure the trains will have ample clearance. The machine is called a "templet." Left—A finished track job.

In the first place, this trough offers an excellent method of drainage. All the water in the subway runs into it, and flows down to permanent sumps which the construction contractor had built. Another surprising value this trough has is that at stations, if people should fall off the platform or be pushed off by the tremendous crowds during the rush hour, they can roll into these troughs and thus escape the onrushing trains.

When the ties were laid, both in ballasted and concreted types of track, care was taken that every fifth tie should be considerably longer than its neighbors. Why was this? Well, it is on these longer ties that the third rail, which carries the power to run the trains by, are laid. The third rail is much lighter in weight, but equally perfect in design. It is installed at about the same time that the rest of the track equipment is put in, and by the same contractor. He also has to *bond* each section of the third rail. This means that he must make a special metallic connection between each section or rail, so that the electric current which will run along the rails will not be interrupted at any point. If such a break were to occur, serious short circuits would happen, bringing about bad fires and other disasters.

In addition to these major installations of ties, concrete, track and third rail, the same contractor puts in the numerous hollow-tile conduits which will be needed for the carrying of wiring required for the correct running of electricity through the third rail. He must also arrange for places in such concrete as he had poured where special signal equipment can later be installed. He must furnish automatic heaters at switch points, which will in cold weather serve to keep the switch joints unfrozen and able to do their work. There are many other kinds of minor technical equipment which he must install, in order to insure the efficient running of a subway system.

CHAPTER NINE

INSTALLATION OF SIGNAL EQUIPMENT, ETC.

THERE are half a dozen other types of installation, in addition to the final and very important one of signal equipment, which still have to be put in to the subway. Most of these have to wait on the completion of the track work; but one of the big jobs can be done at the same time. This is station finish.

STATION FINISH

A builder, much like one who would be working on a skyscraper, gets the job of finishing the stations. His is a relatively simple matter of putting in stairs and stair treads, tile for the walls of the station and smooth cement finish for the floors, plumbing and lavatory fixtures, and the like. The cement flooring is laid directly on top of the rough concrete platform furnished by the construction people.

Other types of work done by the station finish outfit is the installation of change booths, automatic nickel-in-the-slot turnstiles and special exit doors. They put in all kinds of grilles, railings, cement panels in the walls where advertising posters will be put up, enameled name plaques which indicate the name of the station or directions to exits, special steel edges to the platforms, and a multitude of minor and

fairly simple things along those lines. It is a job which takes quite a bit of time, but nowhere near the engineering skill required for construction, track installation or signal equipment work.

FURTHER INSTALLATIONS

Half a dozen or more minor specialized contracts are at this time given to companies which have had special experience in the particular field involved. These include the putting in of special telephone systems for subway workers; drainage systems, including large power pumps which may be called for at areas where great amounts of surface drainage may be expected; ventilation set-ups with power fans and blowers, air vents and special equipment for ventilating lavatories, and so on; lighting equipment for the stations and for the smaller amount of light needed between stations; and a special contract for *bonding* which needs separate explanation.

We have explained the bonding of the third rail as a method of making the tracks continuous, even across the places where two track ends come together, by arranging wires between those two ends. Now, the bonding which is to be done under the special contract mentioned involves two other types.

In the first place, as anyone knows, you have to have a *circuit* in order that an electric system can work. The circuit for direct current, which is used for power in New York's subways, demands one set of rails (the third rail) which carries the positive charge, the charge which feeds the motors of the trains, and another set which will carry the negative charge, thus completing the circuit. Now the negative charge is not dangerous. You cannot get a shock from it alone. So



Station finish. A row of automatic turnstiles, operated by a nickel in the slot, is shown above, together with a specially built-in change booth, just beyond the turnstiles. That type of change booth is no longer used on the new subways. The one shown in the picture below is standard equipment nowadays.



what is done is this: one of the *running rails*—one of the rails the trains run on—is bonded just like the third rail, so it can furnish a continuous system for the negative juice to go along, thus completing the circuit! In other words, when you are riding in a subway, one of the rails you ride over carries heavy charges of electricity, whether you know it or not. This rail is called the “negative rail.”

When a train of subway cars starts out, an arm, which is strangely enough called a *shoe*, located directly underneath the motors, comes in contact with the third rail and picks up the juice, transferring it to the motor, which then starts working at pulling the train along. Most modern subway trains are made up of from six to ten cars, each one of which has two motors in it—one at each end. And each car has four shoes—two on each side. Whenever a train is to start, the motorman in the front car pushes a handle which starts—not only the motor in the front of his car where he is, but *every other motor in that whole train!* In a ten-car train, then, twenty motors are all working at the same time to bring it up to the high speeds now usual in modern rapid transit railwaying. If this system of two small motors in each car, twenty in a ten-car train, was not used, it would mean that our modern subways would have to be run by means of enormous electric locomotives like the ones they use on electrified portions of the regular railroads. And this would be expensive and inefficient, in a system where hundreds of abrupt starts and stops must be made, and where the switching of monster engines from one end of a train to another at each end of a subway line would be wasteful of time and effort.

While one rail, the negative rail, is used to complete the circuit for the power system, the other running rail is used to complete the circuit for the signal system. This system will be described in the following



A station entrance. It is built into a regular building alongside stores. Entrances used to be from sidewalk stairways, but now they are through such buildings as in the picture above, whenever possible, so that the sidewalk can be kept clear of obstruction. Below is a view of a finished station, showing the advertising plaques in the walls.

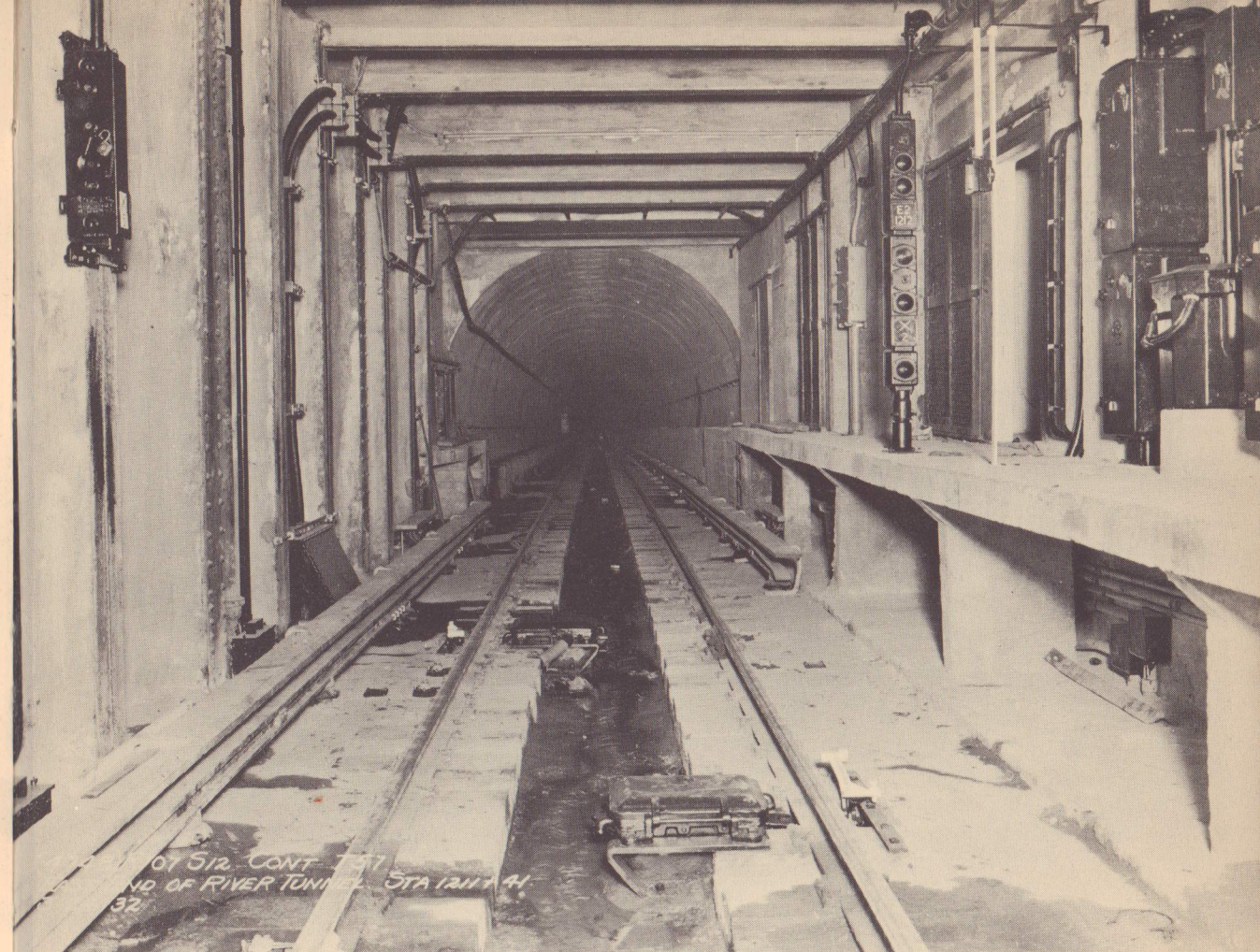


section. Here the bonding is done in sections, rather than in a continuous line of track. At least once, and usually two or three times, in each signal *block* (the area between certain sets of signals) the signal bonding is broken into with a transformer, which lies right at the side of the track. And when the wheel of a train passes over this transformer, it makes an electrical contact which automatically changes the signal lights. Maybe you have wondered how it is that a signal light will turn from green, as a train approaches it, to red after it has gone by it—well, that transformer, set correctly into the signal rail bonding system, did the job more efficiently and accurately than the old-fashioned hand-operated signal systems ever could have done.

THE SIGNAL EQUIPMENT

The signal equipment itself is perhaps the most marvelous and most complicated of all the types of work done in railroading of any kind. It is the product of thousands of men's inventiveness and ingeniousness. A tremendously technical arrangement of automatic devices has been worked out over a period of years which has at last made subway riding, as well as regular train riding, pretty nearly the safest occupation you could take up in all the world!

The signal equipment is expensive, too. For one mile of subway it costs about \$120,000, and it involves the installation of eight major types of equipment over a period ranging from eight to fourteen months for each section of signals. The manufacturing itself, done by other contractors, takes less time since most of the equipment is standardized and can be ordered according to standard requirements.



Here is a picture which shows the signal equipment completely installed, as well as the third rail. In the foreground you will see, at the right of the right-hand rail, the "trip" which serves to stop the train if the motorman runs past the signals. A signal box, with its green, yellow and red lights, can be seen up on the platform, with the number "E12-1212" painted on it. In front of the signal box is a collection of miscellaneous cabinets which contain fuses, electric switches, and other such technical equipment. You will also note that the picture shows the joining of a tunnel section and a regular "steel bent" type of section.

The signals really supply the nerves and the brain to the system of bones, arteries, and organs which have previously been built in the subway. Without signal equipment the subway could not live and run safely, nor could it operate at any degree of speed.

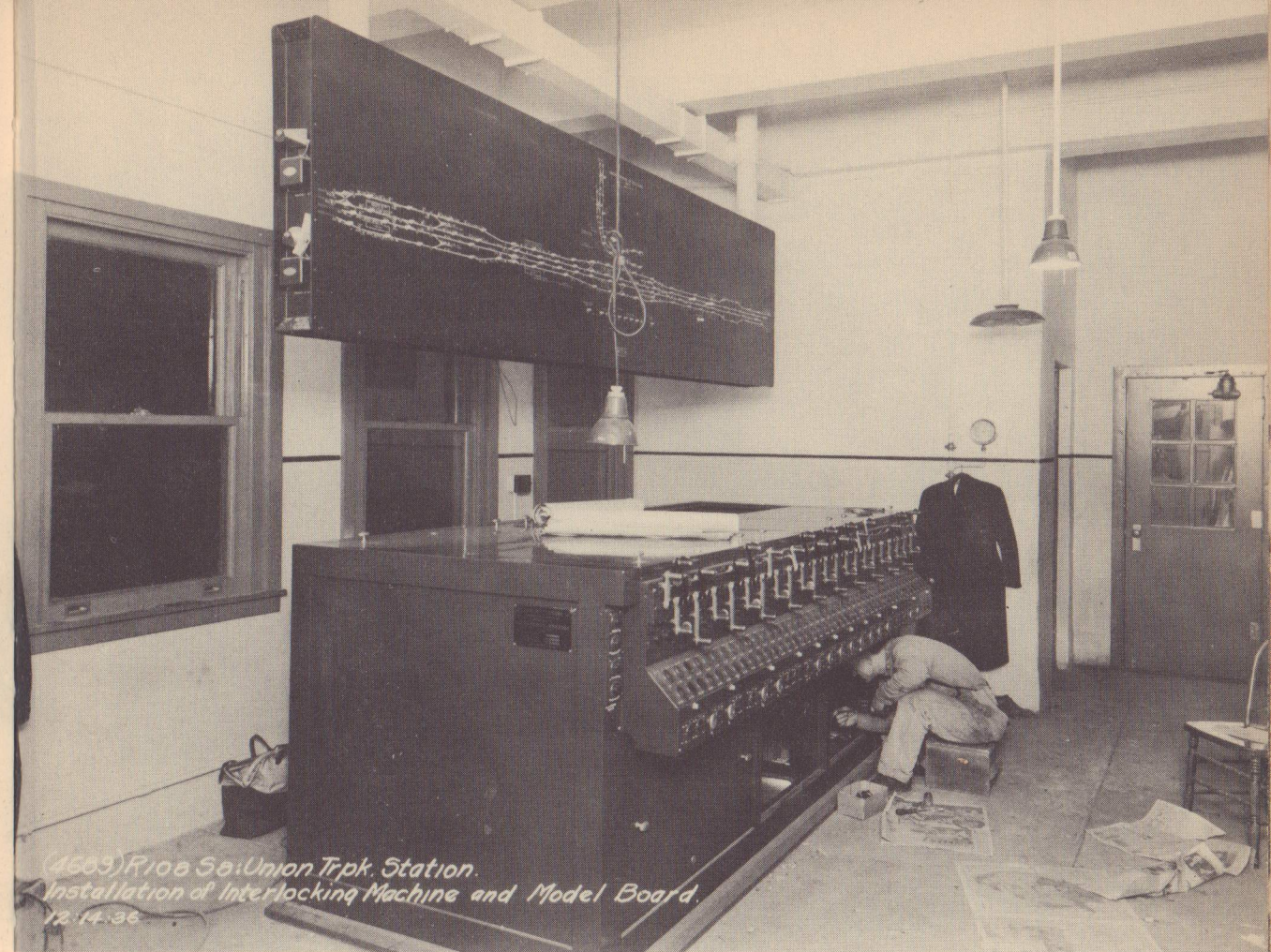
The first type of installation is, of course, the signals themselves. These are assemblies which include the black boxes which you see along the tracks every so often, containing bright red, green, and orange lights. Green means—"Go ahead"; orange means—"Go slow"; and red means—"Stop."

Numerous kinds of special wiring and cables must be furnished to connect these signals up and make them work. The system used is more or less like that on any railroad, except that even more precautions are taken and more safeguards installed. And here is how the system works:

A train starts out from a station and passes a signal. Immediately the signal turns from green to red; the one next behind it turns from red to orange; and the one behind that turns from orange to green. Every time a train passes a signal, *three* signals change—one from green to red; one from red to orange; and one from orange to green. The area between each signal is called a *block*; and modern signal equipment is so arranged that a train coming along behind the train moving ahead will get a warning signal while still two full blocks behind.

But suppose something has gone wrong with the engineer of the second train? Suppose he has been taken sick? Or that he didn't see the signal? There would be a chance of a horrible smash-up.

But smash-ups do not occur. Because a special kind of equipment is installed at each signal; and whenever the signal is set at red a small



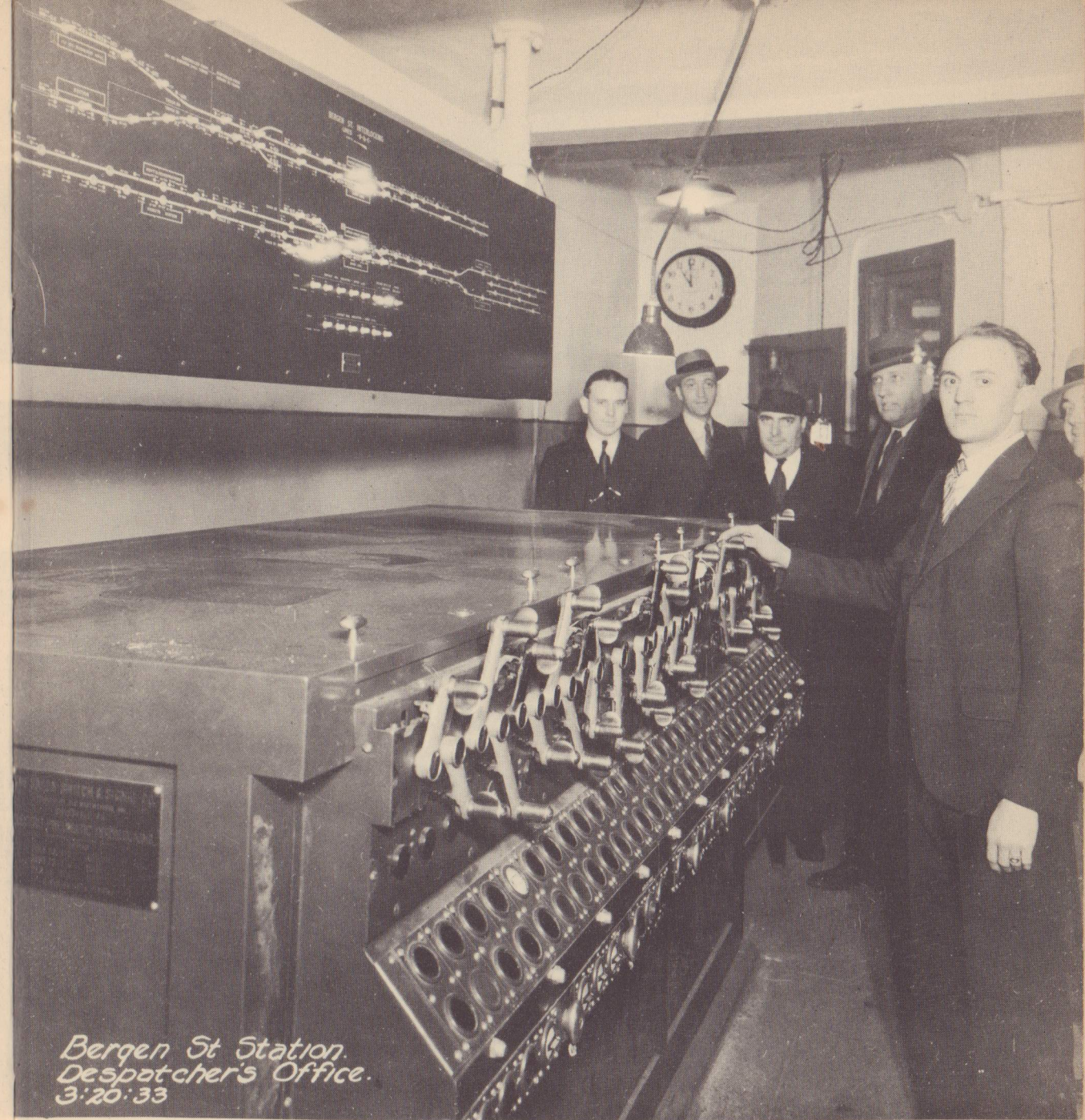
The heart of the signal system. Above the huge box with all its switches and handles, you will see the long "model board" suspended from the ceiling. This model board is a complete, accurate miniature model of a whole signal section of subway—the section which this particular signal room controls. Every place where there is a signal in the actual subway itself, there is a tiny electric bulb placed on this model board. And when a train goes past the signal out in the big subway, the little bulb flashes on here, showing the "dispatcher" (see next picture) exactly what signal block the train is in. The "interlocking machine" (the big box standing on the floor) works the signal and switch systems of the subway.

trip close beside the track springs up automatically so that it reaches several inches above the track. Now suppose a train rushes along out of control or at least with the motorman unaware of the red signal. He lets the train run past the signal.

What happens? Well, directly beside the first wheel of the train, right under the motorman's car, is located a *trip valve* which extends down from the wheel truck toward the rail. The automatic trip, activated by the red light of the signal, is standing up. As soon as the train passes the red light, this trip hits the trip valve and pushes it up, whereupon the valve forces on the air brakes full pressure!

The brakes apply so much stopping power that the automatic power breaker, which is a part of every motor in a train, is brought into use. The power turns off, the motor of the train stops working, and the brakes bring the train to a sudden and startling halt—with all passengers jostled and angry, perhaps, but safe and unharmed.

In addition to the signals, the cables and wiring, the automatic stops, and the complicated interlocking apparatus which makes the system work, the signal contractor has several other types of equipment to install. Among these are switch mechanisms which enable operators sometimes half a mile away to set the switches by remote control. Then there are the transformers which step down the alternating current used to operate the signals, the lighting systems, and the switches of the subway. The use of direct current is limited entirely to the power supply for the third rails. All other electrical current in New York's subway is alternating current; and the transformer rooms are used only to adjust the amount and the strength of the current to the various tasks it must do.



Here the interlocking machine (in a different dispatcher's office) is completely installed, and the system is working. Note the lights on the model board. They indicate where the trains are, and the handles of the interlocking machine are used to guide the trains along their route by changing the signals and switches as they go—automatically, of course, but the interlocking machine itself serves as a check on the automatic operation of the signals.

Finally the same signal installers put in various illuminated station markers, special platform bells to tell train motormen when to start, and such illuminated signs and markers as go along with the signal equipment.

FINAL TASKS

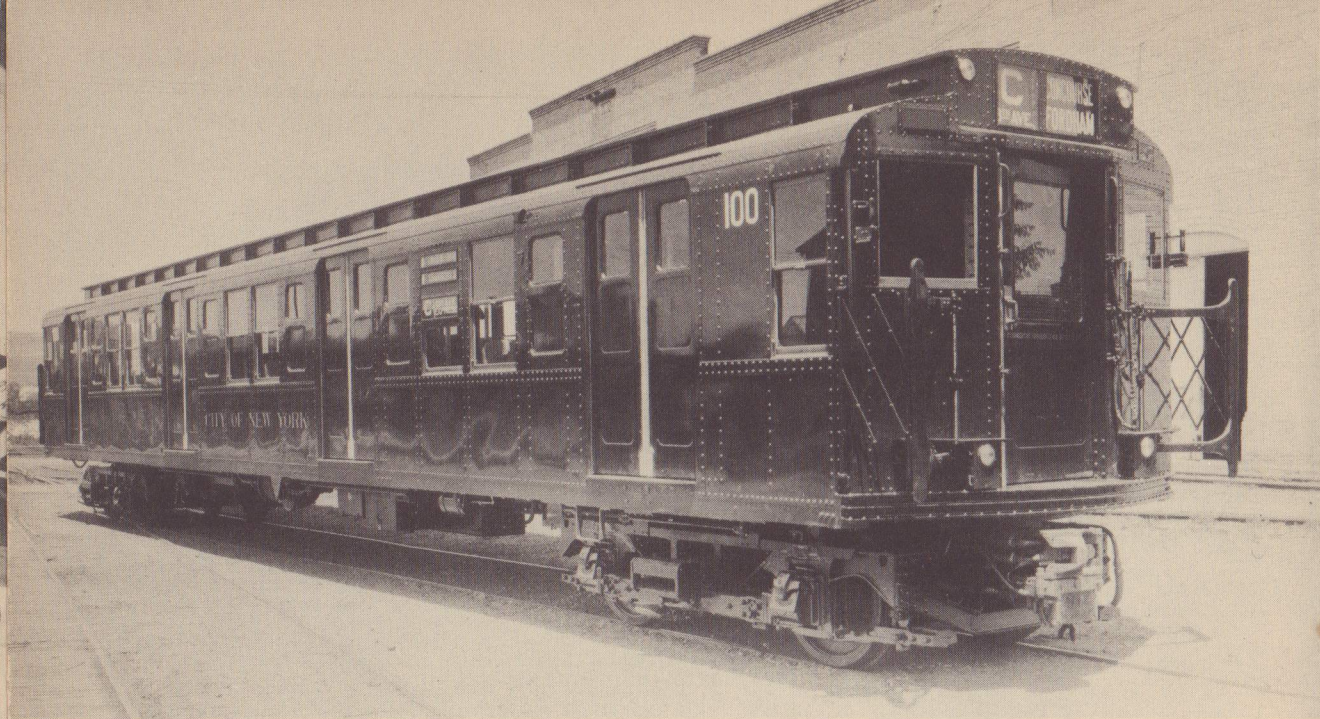
The last installation is, of course, the *rolling stock*, or cars with their two motors, their brake systems and other mechanical devices. The cars which make up a train of a New York subway are specially designed to hold as many people as possible, sitting and standing. On the Independent Subway system alone there are 1,497 such cars, and new cars containing new refinements of design are always being added as traffic increases and as new sections of the subway are being opened.

New and old cars all come into the new subway section either down long inclined ramps from the *yards*, if the new section connects directly with one, or else they run into the new section right from one already existing with which the new one is connected.

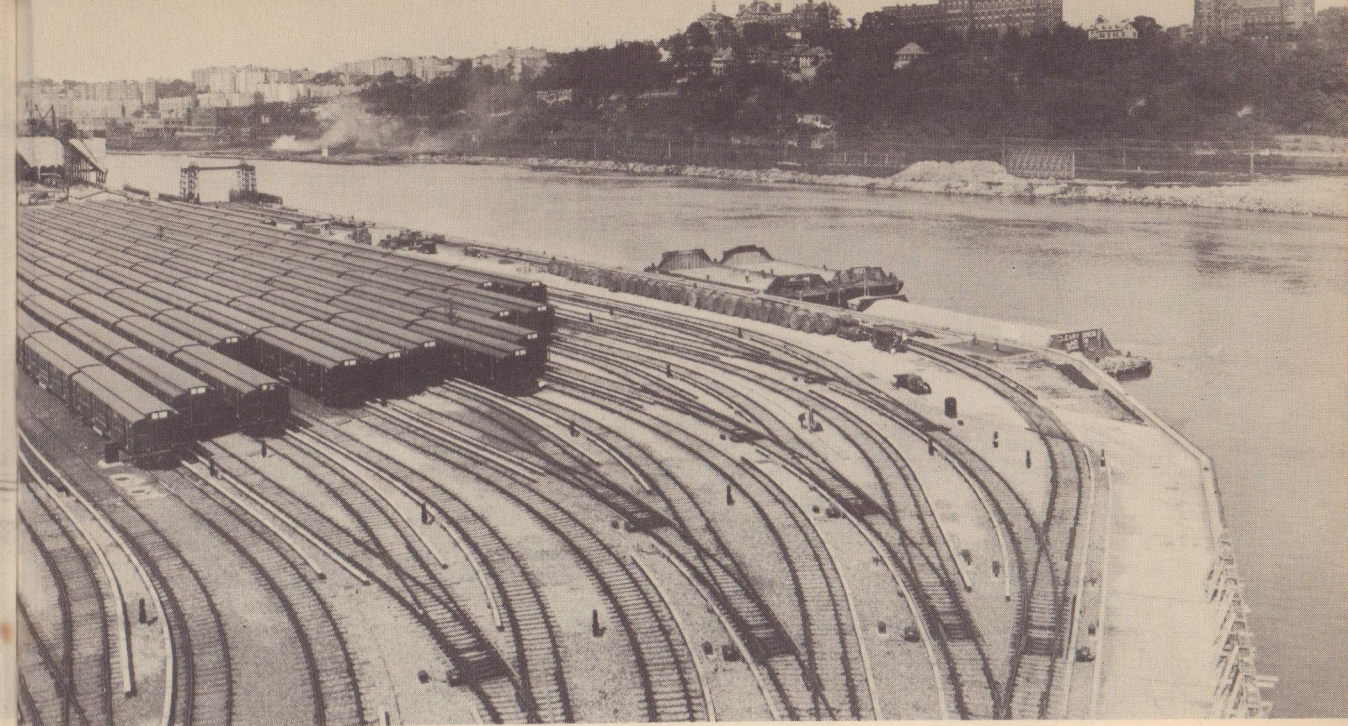
Now the yards themselves, where cars are stored, repairs are made, painting and cleaning are done, and the conductors and motormen get their pay, are built separately from other subway sections, and are always constructed at the very start of any new subway system. They are located on the surface, not under ground, and lie far out of the city, in some relatively unpopulated area. Their most striking feature is the miles and miles of storage track, which fan out much like the typical freight yard tracks of a railroad. The yards are not "subways" at all, of course. They service the subway, but their con-



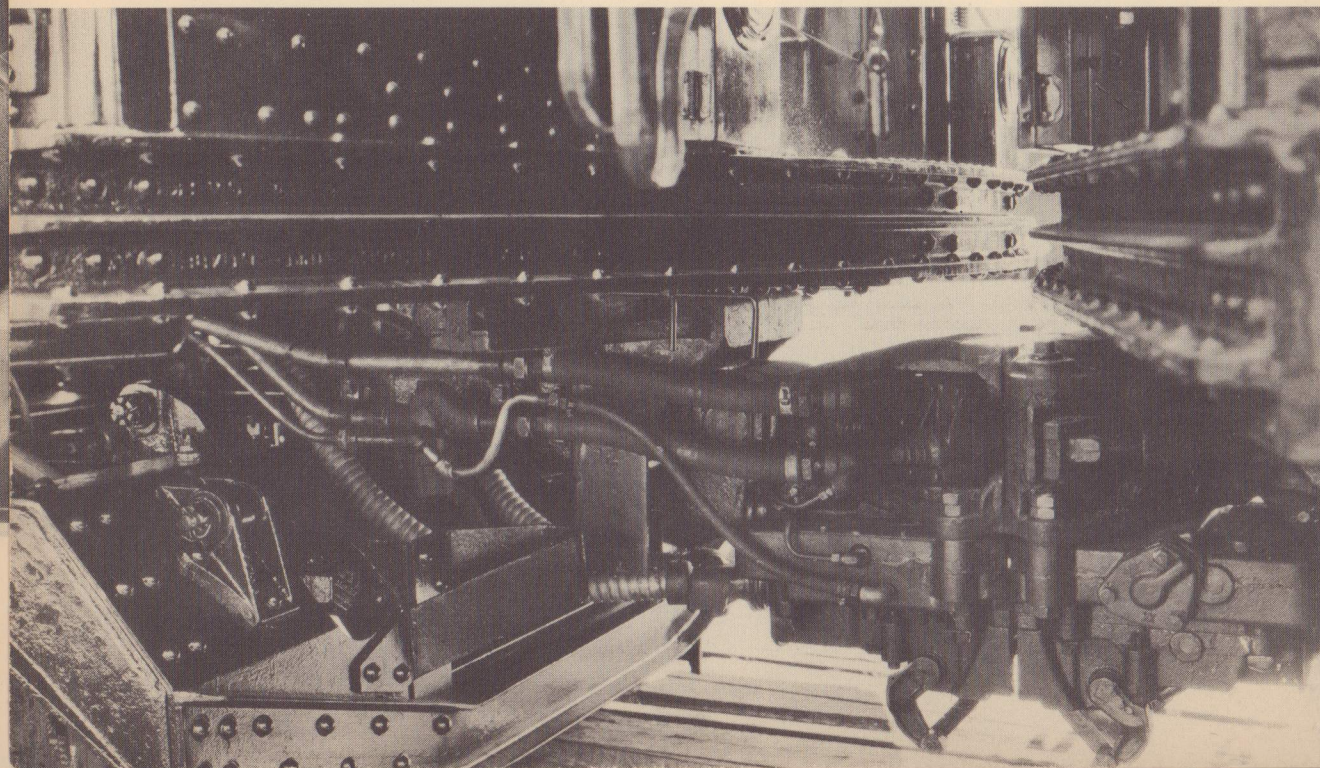
The inside of one of the huge new Independent Subway cars. It is nice and shiny when newly painted and washed and polished—but that won't last very long, when thousands of people begin crowding into and out of it on their hurried tasks.



The same type of car as in the previous picture, as it looks from the outside. This and the picture previous were taken in the subway yards, up on the surface of the ground. Below, a picture showing the amazingly complicated system of couplings between two cars.



A bird's-eye view of the subway yards. Below—A yard engine hauling some new subway cars. Note the row of switch mechanisms in the foreground. They are still crated, you will note, and are waiting to be installed down in the subway as soon as they are needed.



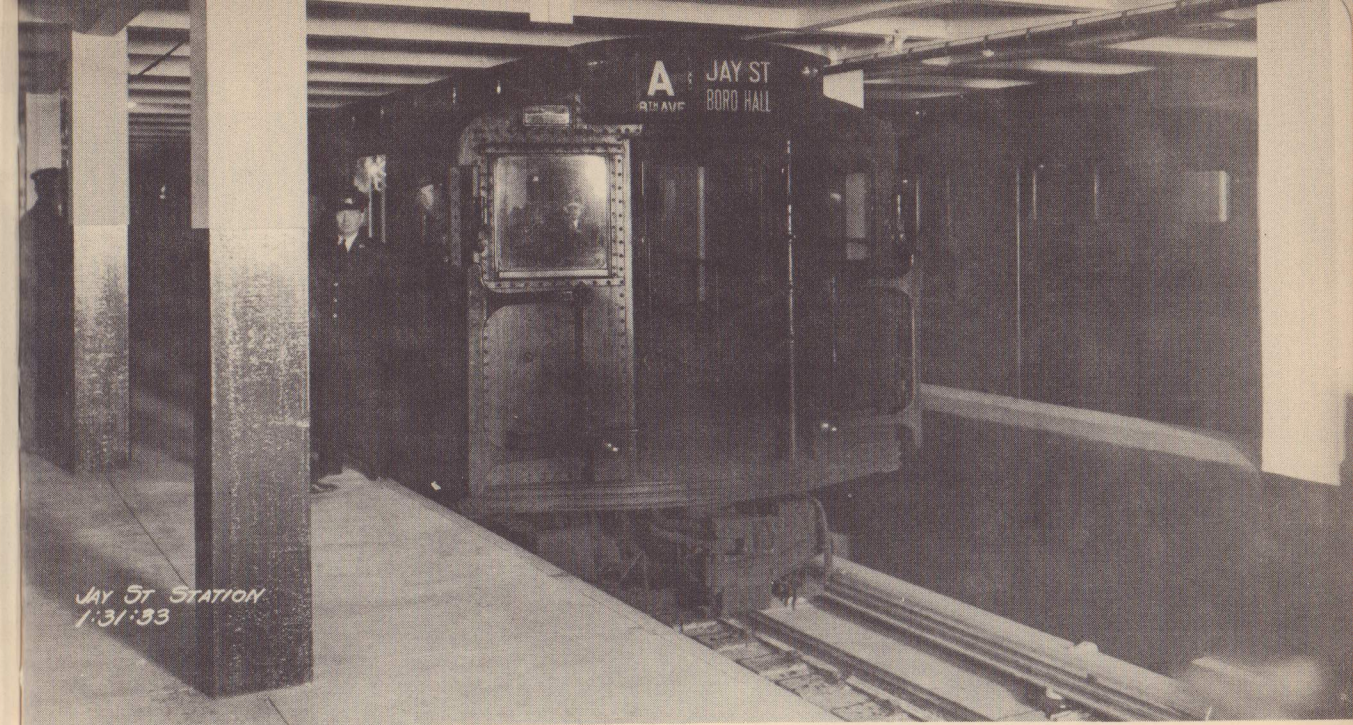
struction involves none of the processes we have described in this book, except track laying (ballasted track is always used in these yards) and signal installation.

So now, when the signal contractor has finished his work, the actual building of a subway section is just about finished—three, four or five years after that long-ago day when we found a boring crew drilling for earth or rock samples along the proposed route.

All that remains to do is the testing, cleaning, polishing, testing—and more testing. The operating department of the Board of Transportation now takes over, and comes into the new subway section. The engineers of the department conduct thousands of tests over a period of weeks or even months, in order that they can be absolutely sure that the job has been done right, that everything is safe, and that no catastrophes can occur through lack of excellence in the workmanship or lack of care in the design.

The technicians test equipment, signals, tracks, grades, curves, switches, lights, and all the other parts and materials which have gone into the subway. They even flood the sewer and drain systems, to be sure that they will do their job. Trains are run through at full speed, in order to make sure that the rocking from side to side of a train traveling at a fast clip has been sufficiently allowed for, and won't cause it to bang up against the wall on some long curve or at some switching point. Everything is checked and rechecked, until—

At last, comes opening day! A train of political luminaries is piloted down the new route, with the mayor at the controls, perhaps. Speeches are made, a symbolic ribbon is cut—and soon after this the first regular passenger trains begin their carefully scheduled runs. Nickels click into automatic turnstiles; passengers buy newspapers or candy or maga-



At last—the train rolls into the station, and the work is done. Note the motorman peering out of his little stall in front of the car. Below—Part of the opening ceremonies for the new Independent Subway was the operation of a train by the Mayor of the City. Mayor LaGuardia, with a motorman's cap on, is seen at the controls of the first official train.



zines at the new newsstands, which are run by a private firm that has bought the concession for them from the city; trains fill up to suffocating density at rush hours as commuters to outlying areas of the city try out the new, swift and more convenient method of travel.

Soon the subway becomes a familiar convenience, its mysterious construction and the marvelous engineering feats performed in its building completely unknown to the citizens who daily crowd its cars.

But we, who have been on this tour through a growing subway structure, will not forget. We won't forget the magnificent science, the logic of planning and designing, the swift, marvelous efficiency, which developed this amazing underground railway. We won't forget the splendid strength and skill of the workmen themselves—surveyors, designers, draftsmen, muckers, diggers, drillers, blasters, carpenters, masons, steel men—who put the subway through from the first few lines on a piece of paper to the final result: sturdy trains roaring through the tunnels with their loads of precious human freight!

CHAPTER TEN

SUBWAYS AROUND THE WORLD

ONLY sixteen cities in the world have rapid transit subway systems and most of them are very small. Only the largest, busiest, most congested cities can afford to build subways—or are forced to build them by the crowded conditions of the streets even though they cannot “afford” them.

However, more and more cities are now undertaking the construction of underground railways, for the experience of those places which have had systems in operation for many years has proved beyond a shadow of a doubt the value of subways as means of speeding up human traffic and decreasing congestion.

But no city, with perhaps one or two exceptions, ever builds a subway until its growth has reached a point where it is impossible to move on its streets with any ease. Subways are too expensive, too complicated, and too tremendous a construction to be undertaken unless necessity forces a city to do it.

LONDON

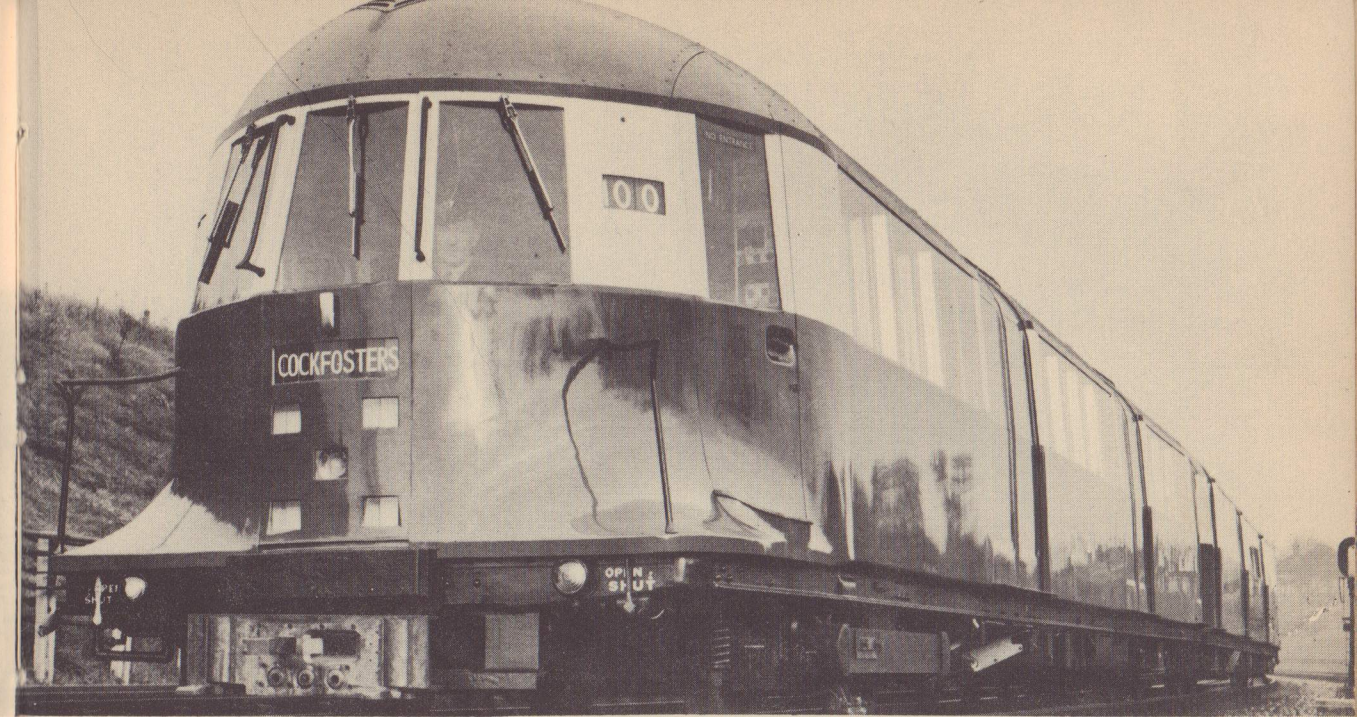
In the 1860's London, which was at that time the largest city in the world, was the first to plan and build a subway. Its first subway was

really just an underground extension for through steam-train lines, though it proved very valuable to people in the city, too. It ran between two important railway terminals so that people who wanted to pass through London could do so without taking hacks across the city. This first route was called the Metropolitan Railway and was only three and three-quarter miles long. You can imagine the smoke and soot that filled that tunnel from the steam locomotives, even though "smoke-consuming" engines were used.

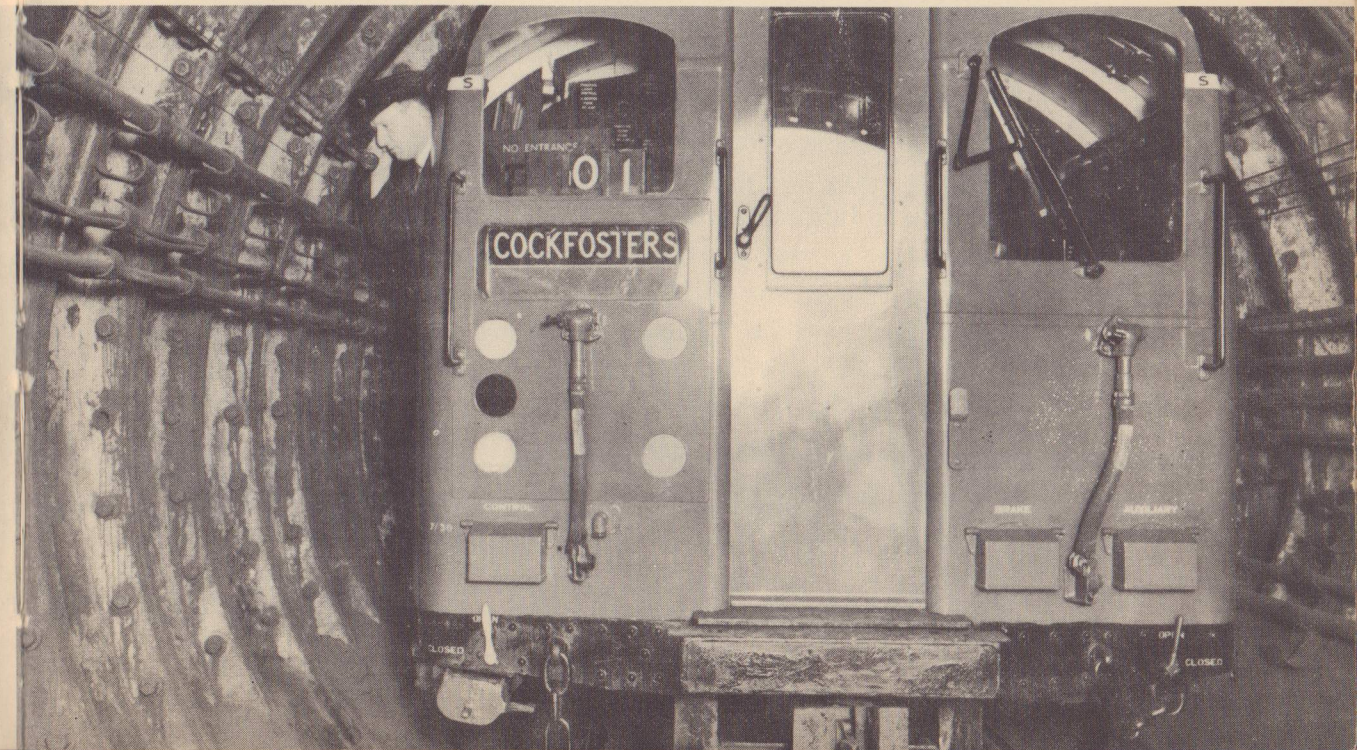
Even so, the first subway proved highly successful and London followed it up with many miles of new subway routes—including the first electrically operated subway, The City and South London, opened in 1890. It was in driving tunnels under the Thames River, while building this subway, that shield tunneling with compressed air was first used in world history. Indeed, London's subway system embodies the first development and use of a great majority of modern subway construction and operation techniques we have described in this book.

Building of subways in London has never stopped. Today the city has over seventy-nine miles of actual subway structure in addition to several hundred miles of surface track out in the suburbs. And many more miles of subway lines are under construction or are planned for construction in the near future. We may think that New York is a congested city, but only the Londoner can tell you what real congestion is! To London, with its narrow, winding streets and its confusing planlessness, subways have been a salvation.

Practically all of London's subways have been built by the tunneling system, with or without compressed air. London's subsurface is largely clay so that tunneling is the most feasible method. Londoners call their tunnels "tubes."



A modern, streamlined London train. It is adapted to both surface and subway running, since much of London's rapid transit system is on the surface. Note the windshield wipers—and the motorman inside his capacious booth. Below is a London train built for use in subways alone. Here the motorman is talking with the dispatcher's office by special subway telephone. (Courtesy of the London Passenger Transport Board.)



Of course, the success of London's subway set other cities suffering from the same problems to think of constructing underground railways. New York, for instance, first tried to build a subway way back in 1869, when a man named Beach actually built a short sample under Broadway. His system was to be operated by pushing the trains through smooth tunnels with compressed air! We don't know how well the sample would have worked; all we do know is that Beach could not find the money to continue his system and so New York turned to elevated railways instead and did not get around to building its first subway until 1902.

GLASGOW

The next actual underground railroad built was in Glasgow, Scotland, a busy industrial city. Here a suburban steam-train line, which included two miles of underground route through the center of the city, was opened for business in 1886. It was really not a subway as we understand it since its tracks ran for the most part on the ground level, going down into the tunnels only in the most congested part of the city. The same is true of Glasgow's second rapid transit system, the Central Low Level, which opened in 1896 with seven and a half miles of tunnel.

But in 1897 the Glasgow District Subway was opened, and this was a short line of six and a half miles entirely under ground, built in the form of a loop around the city. It is a very deep-lying subway, parts of which are 155 feet under ground. And it has another distinction in that it was the only cable subway ever built. For years its trains were pulled through the tunnel by means of heavy cables. In fact, it was



A view of a London station. London subway riders have to buy tickets when they go on a subway, for the fare in that city varies with the length of the trip one plans to take. This is quite different from New York, where the fare is the same no matter how far you want to ride. In the picture, at the left, you will note a bank of ticket machines with different prices marked on them. "6d" is about 12 cents American money—and 1d is two cents. You can ride between several stations for as little as two cents in London. (Courtesy of the London Passenger Transport Board.)

only in 1935 that its cable system was replaced with regular third-rail electrical operation.

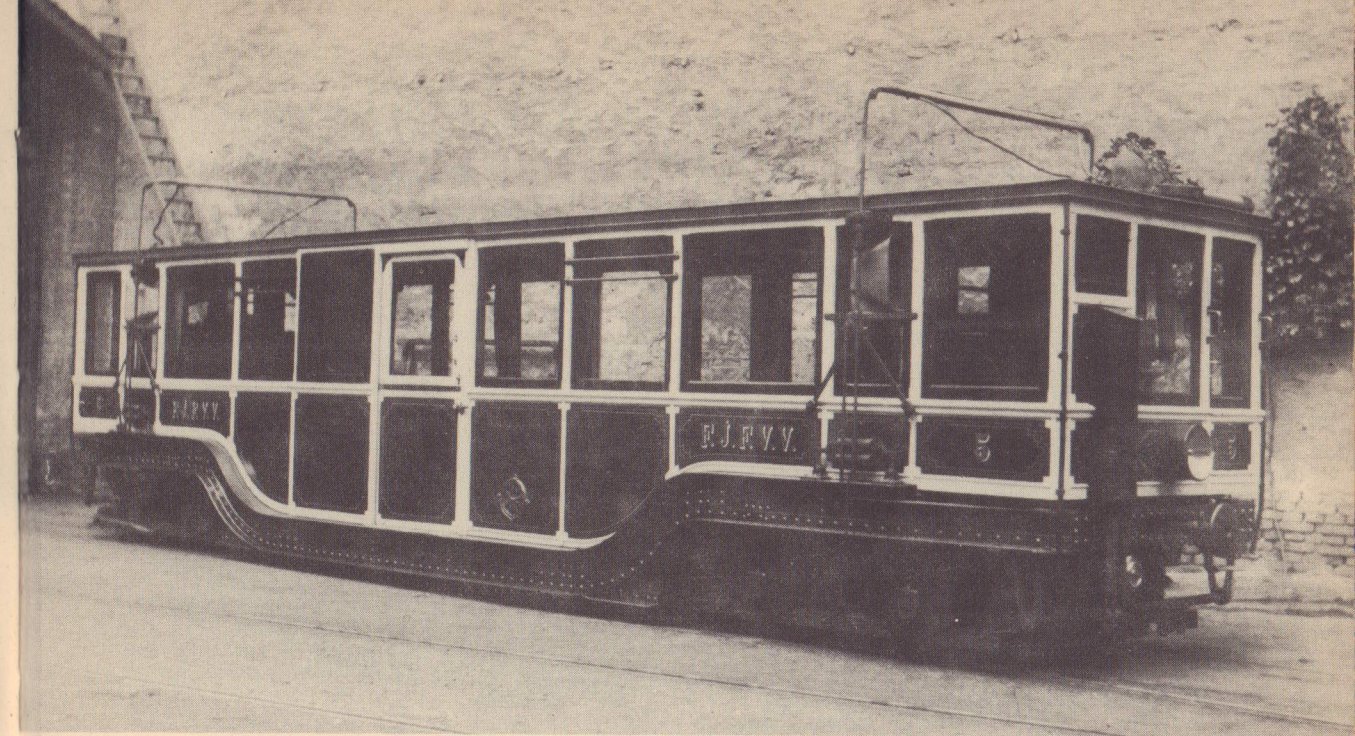
Despite the interest in subways which the London and Glasgow systems aroused, other cities were slow in adopting the new method of rapid transit. It was prohibitively expensive to build and, moreover, though one might not believe it nowadays, millions of people were really afraid of taking a train ride under ground. They thought the roof might cave in, or they might smother to death, or they surely would drown in subterranean floods.

But as the pressure of population in the big cities increased, something had to be done about street congestion. Around the turn of the century, from 1895 to 1905, six or seven big subway systems were started.

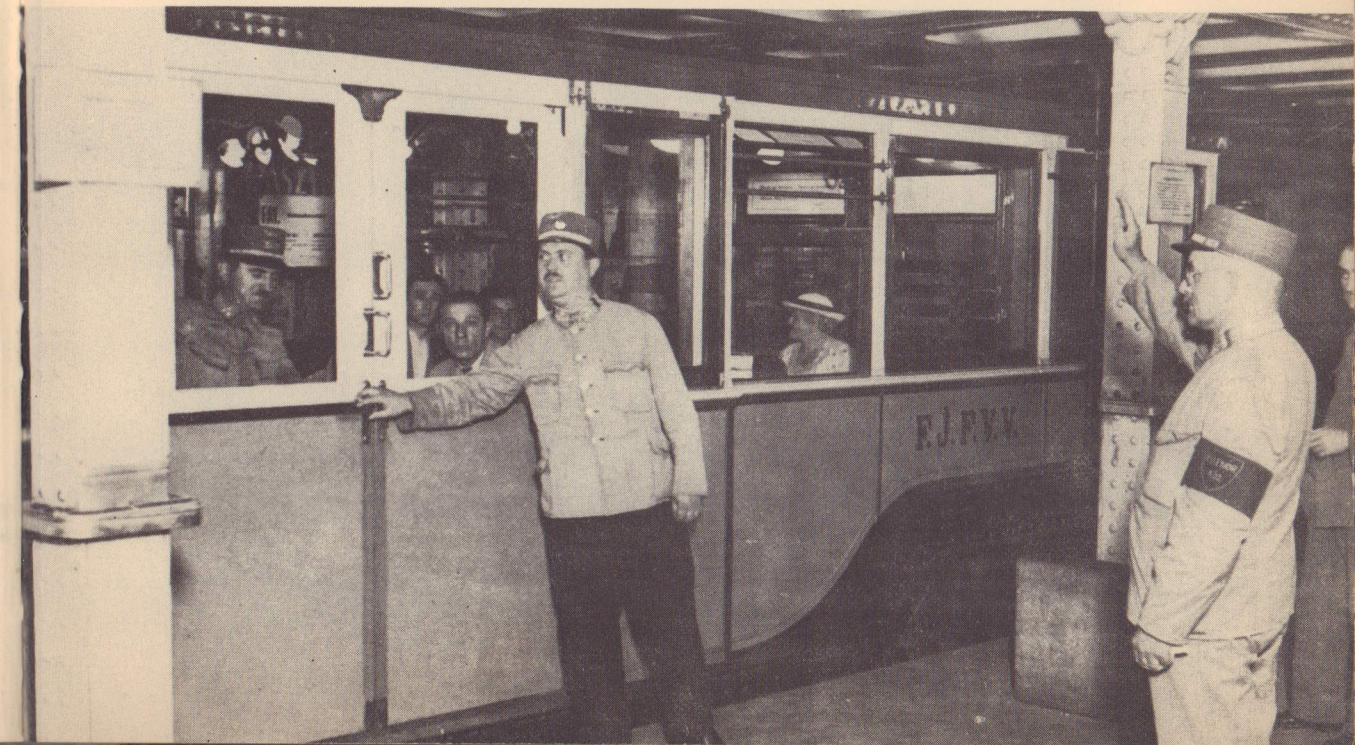
BUDAPEST

The first to follow the Glasgow system was, however, one of the smallest actual underground railways ever built—the Budapest subway. It was opened in 1896 and is only two and a half miles long! This Hungarian subway is used for street cars, although the cars run only through the tunnel and not both underground and on the surface. Thus it is a genuine subway despite the fact that its cars are very much like any surface cars.

This Budapest subway, like the first two Glasgow systems, was built by the cut-and-cover method—a method later adopted by subway builders in many other cities until now it is always used where practicable.



Budapest's subways run by means of an overhead trolley type of electric power, rather than a third-rail. The car above, just coming out of the subway, shows the two power pick-ups on the top of the car. Below—The Budapest train is leaving the station. The man at the right is giving the "Go!" signal. (Courtesy of the Royal Consulate General of Hungary.)



BOSTON

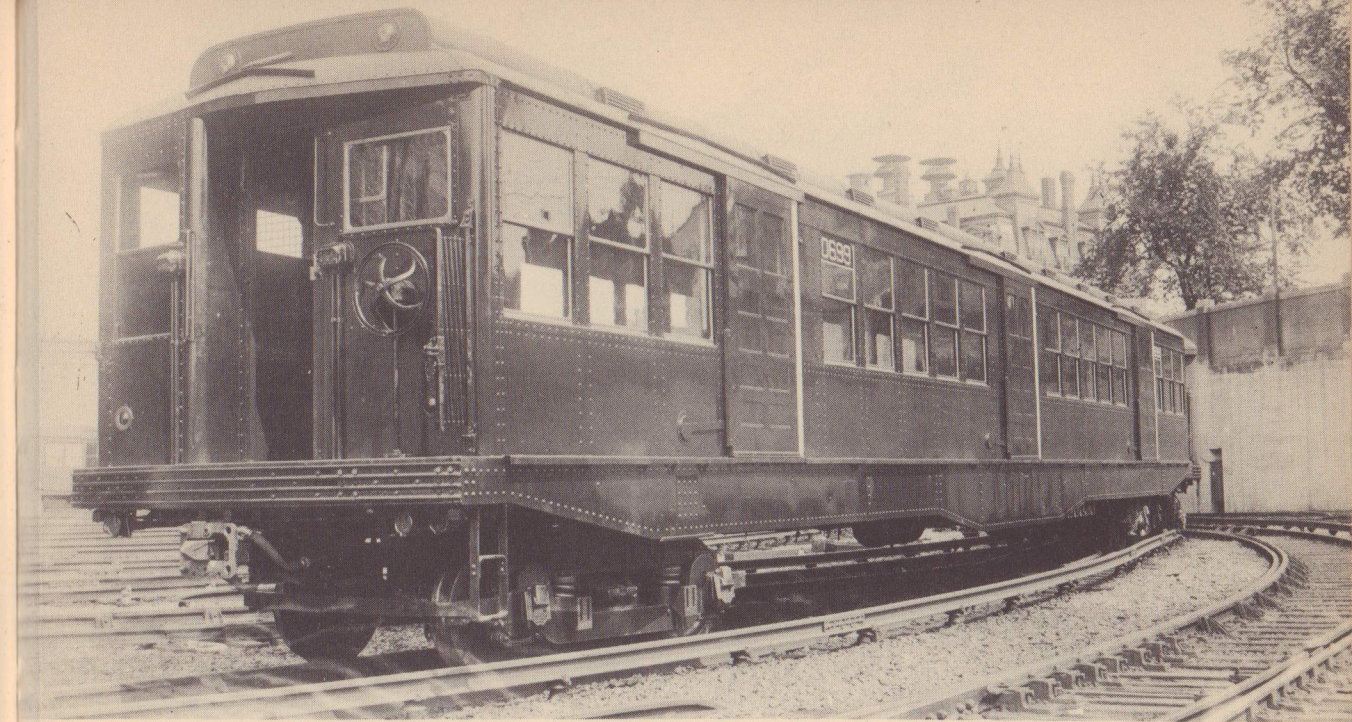
Boston built the first subway system in America, soon after the Budapest subway was constructed. Anyone who knows Boston will understand why it needed subways, at least in the downtown section. Every street, with few exceptions, is narrow and winding and the congestion of surface motor and pedestrian traffic is terrific.

Therefore, in the 1890's it was planned that trolley cars should be taken off the street and put in tunnels at least in the most crowded areas. The first route, only one and a half miles long, was opened for traffic in 1898. Since then, of course, the Boston system has been much expanded and more additions are still being made. All of the new additions, like most of the ones following the first tube, are regular subways such as the ones in New York and London, and not merely "underpasses" for trolleys. And like the New York systems, the Boston lines include many miles of elevated structure, much to the regret of people who want their cities to be quiet and livable places. Elevated trains are, of course, noisy and dirty and their construction has been abandoned practically everywhere now.

Within the next five years, from 1900 to 1905, the original routes of three of the really great subway systems of the world were opened for operation—in Paris, Berlin, and New York.

PARIS

The first link of the Paris Metro was opened in 1900. It was eight miles long. By now, of course, Paris has a really amazing network of



Boston's subway cars are much like those found in New York. Here again the system is both subway and elevated, and the cars run both underground and above. (Courtesy of the Boston Elevated Railway.) Below is a view of a Paris subway station, with its great tile-brick roof and queer curved advertising boards. (Courtesy of the French Information Center.)



subway routes which can take you practically anywhere in the city. Moreover, like all the major systems in the world, it is constantly being extended, especially out in the suburbs.

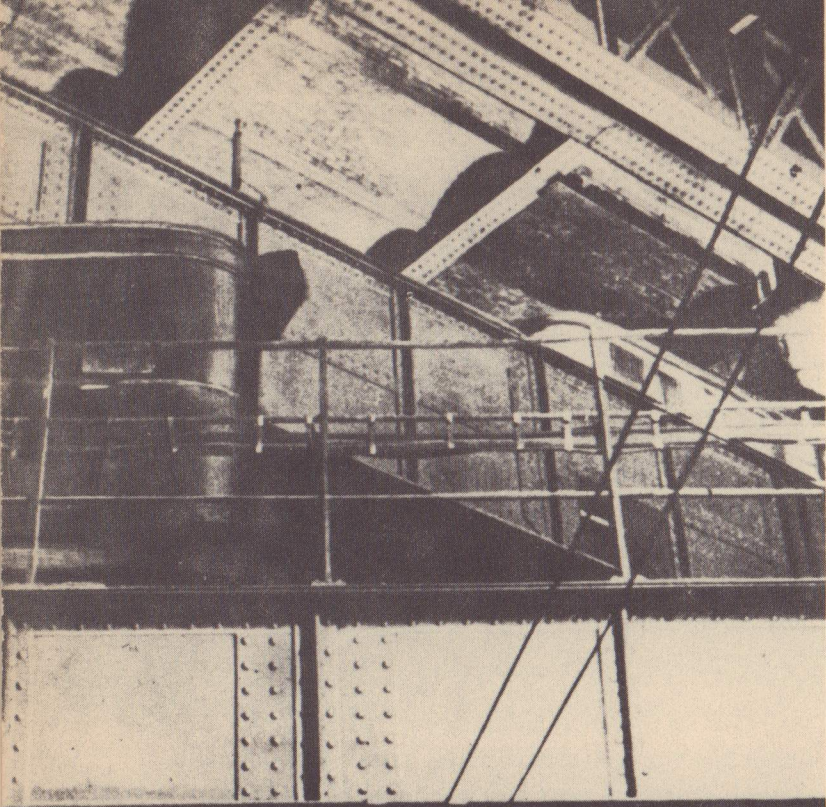
A really interesting variant of subway construction was developed in Paris. You will recall that in the description we gave of the cut-and-cover construction we pointed out that the whole excavation for a block of subway was nearly complete before any construction work was done. Well, in Paris, the engineers always construct the roof of the subway before doing any excavation beneath it! They dig down from the street to the depth where the roof is to be, build the roof, and put its supports in place. When that is done and the road surface is replaced, the excavators dig out the earth and rock still remaining under the roof.

This method seems never to have been used anywhere else though it has always worked well in Paris.

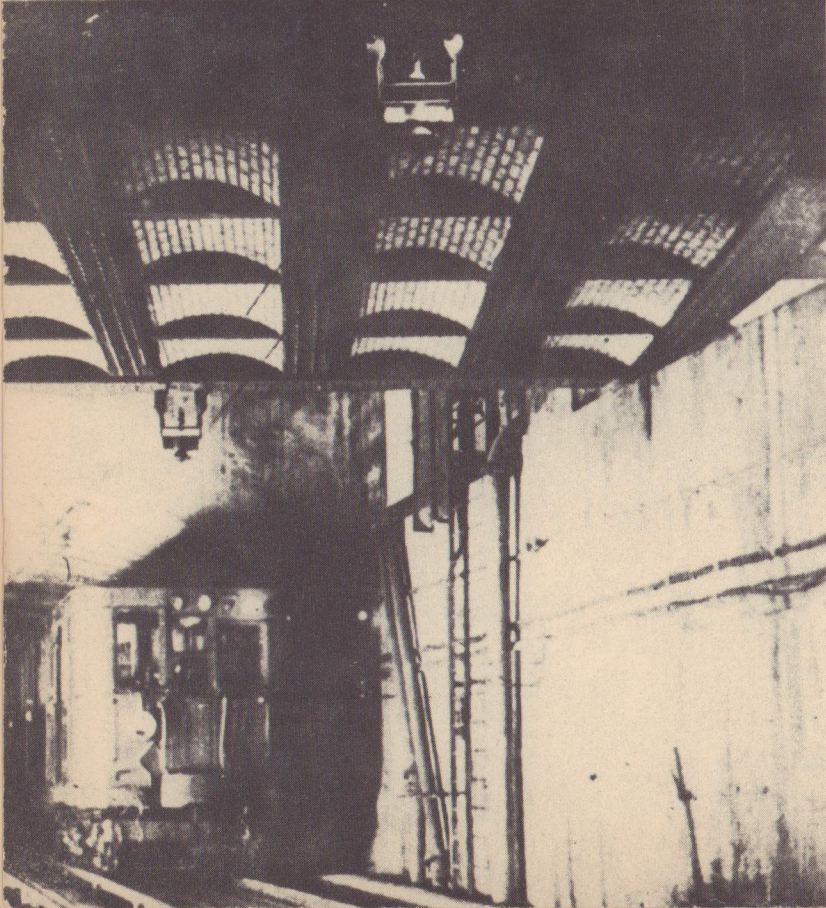
BERLIN

After the construction of the Paris subway came the *Untergrundbahn*, Berlin's thirty-nine-mile subway, which Berliners always refer to as the *U-Bahn*. Its first section was opened in 1902 and several additional routes have been built since so that by now the city has a regular network of high-speed railways. But most of Berlin's rapid transit system is either elevated or on the surface.

Berlin, too, as most all big cities, is abandoning the "el" as an unsightly nuisance in the city. The new lines will all be subways.



A fascinating spot in the Paris subway. The picture has caught trains traveling on three levels at the same time. You will notice the third, highest level if you look carefully in the upper right hand corner. (Courtesy of the French Information Center.)



NEW YORK

Finally in 1904 the first link of the world's greatest system of underground railways, the New York City subways, was opened for business. It had taken four years of difficult and dangerous work to build that first underground, which ran nearly ten miles from Brooklyn Bridge to Broadway and 145th Street. The extension to the Bronx which runs across the upper end of Central Park from Broadway opened about nine months later. The total length of this first operation, when all sections were completed, was over twenty miles.

In those days many miles of the system could be constructed in open cut—especially uptown where there was much less congestion than there is now. For that reason it was possible to build a subway much faster than it is built now since much less care, expense, and labor had to be spent on decking, underpinning, and rerouting subsurface structures, which were much less complicated at that time.

However, construction problems in some of the congested areas down in the business sections of the city were almost as difficult as they are today. The hardest part of the contractor's job was the laying of subway tunnels under the East River and the Harlem River. Sub-river tunneling methods were quite primitive in those days, although the main principles of compressed-air shield tunneling were already in use. Serious accidents happened, as did one in the tunneling under the East River when a "blowout" occurred. What took place was this: The air pressure in the working compartment right at the point where the shield was became too great for the mud and water overhead. The air began to escape through the open end of the shield with so great a



Berlin's subway stations are quite gaudy, compared with the simpler white tile decoration of New York's systems. Note the extraordinary height of the ceiling. At night the outside of the stations, up on street-level, are quite conspicuous with their neon-light "U," which stands for "U-Bahn." (Below.) (Courtesy of BVG, Berlin.)



force that it blew a man clear through the shield and up to the surface of the river!

However, despite accidents and delays, the first big subway in New York was eventually completed and other systems began to grow. A network of lines now spreads out across Brooklyn and the Bronx, and the congestion of subways and tubes on parts of Manhattan has become a confusing maze to the tourist who is not accustomed to the labyrinth of passageways and the different tracks.

The early subway systems in New York—the Brooklyn-Manhattan Transit system and the Interborough Rapid Transit system—include many miles of elevated structure, which are not given in the figures on the route-mile chart on page 210. Only actual subway mileage is given there. The new Independent Subway has no elevated structures at all, with the exception of one bridge in Brooklyn. “Els,” the government of New York City has decided, are too ugly, too noisy, and too cheapening to all the property along their routes—and so no more elevated railways will be built and the already existing ones will be replaced with subways as fast as it proves possible. The new Sixth Avenue extension of the Independent Subway will replace an “el” which has been an eyesore for decades; and a future Second Avenue Subway will do away with two separate elevated lines.

PHILADELPHIA

Philadelphia was the next great city of the world to carry plans for subways to fruition. The Philadelphia system is a relatively small one, being a part of a larger system of surface and elevated tracks just as the early routes in New York were. Philadelphia’s first section of



Here is a different kind of subway station in New York. It houses the mechanism for several elevators, which take passengers more than 75 feet down to the level of the subway! The station is up at Washington Heights, Manhattan, where the trains run clear under a sizable hill.

subway was only two and a half miles long and its total mileage is still less than a dozen miles. But several extensions are partly finished and waiting further financing for actual completion.

CHICAGO

The Chicago subway really does not fall into the scope of this book, since it is not a passenger system. But Chicago's freight tunnels, with their sixty-two miles of tubes all at least forty feet under ground, are so unique that a word about them must be inserted here.

For some reason Chicago has never had a passenger subway, though agitation for one has been seething for the last thirty years or more. That the city has a subway of any kind will come as a surprise to many of Chicago's own citizens—the author lived in this city for a year and a half without ever hearing a word about it!

The tunnels are unique in every way. In the first place, they are very small in diameter, as the photograph here shows. The track is only two feet wide, just about the same width as the industrial track which construction contractors use to move excavated material in subway tunnels. Further, the digging of the tunnels was nearer to a sculptor's job than anything one can think of, for most of the mileage was *carved* through solid masses of dense blue clay—carved with sharp, oddly shaped knives that sliced off big pieces of the clay and thus slowly formed the tunnels.

It is a subway almost without stations, for there are only four public receiving stations on the whole system. These are depots where manufacturing concerns bring their packages, crates, and bundles for shipment through the tunnels to the numerous private outlets at major department stores, hotels, railway stations, and such places.



Chicago's queer freight subway. The picture above shows how small the tunnels are, barely big enough to let the cars through. Below, the "X" marks the place down which the refuse which resulted from the tearing down of an old building on this site is dumped. Underground it is carted off to disposal points far away. (Courtesy of the Chicago Tunnel Co.)



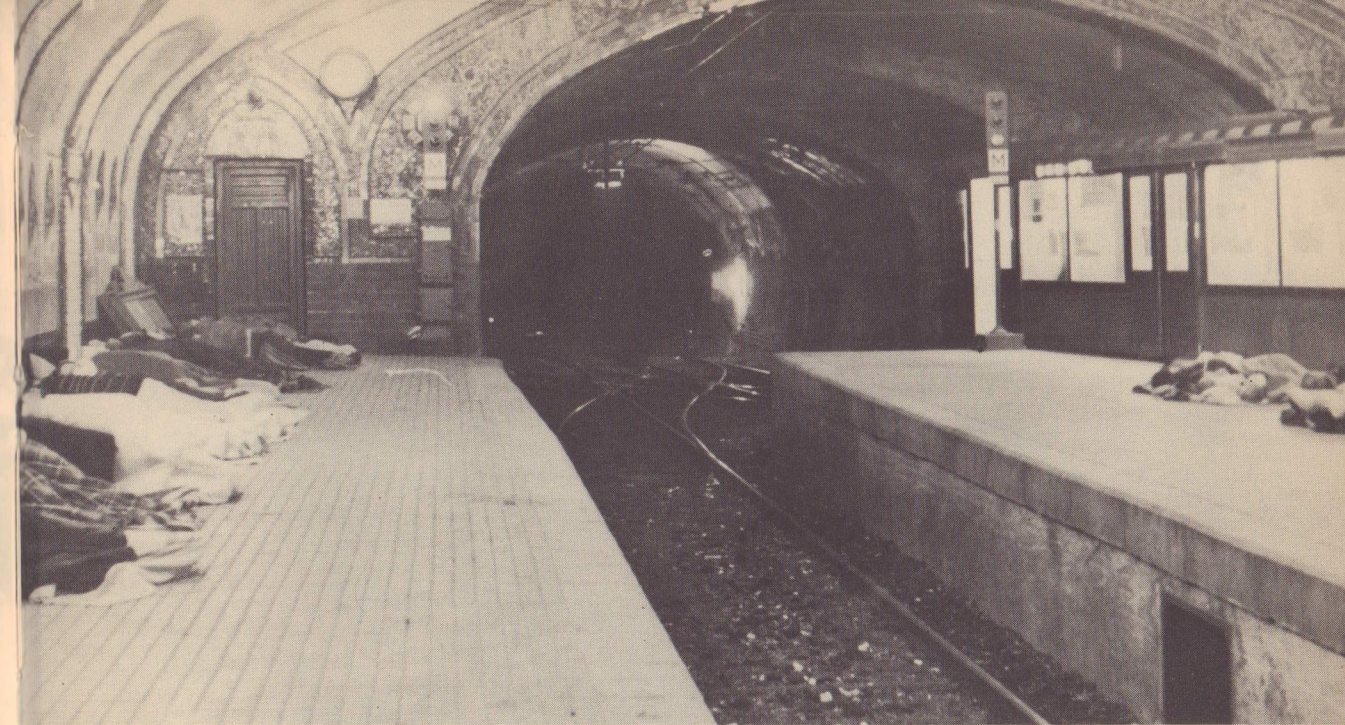
No passengers ever travel on this subway, as we said before, just bundles and crates, and thousands of tons of coal and cinders brought to and taken from large office buildings and hotels. One of the subway's biggest jobs is the removal of debris from torn-down buildings and bringing building materials to buildings that are being constructed.

The whole system of Chicago's freight subways runs as a fine network under an area which is probably less than a square mile in total extent. There is a tunnel under almost every street in the whole congested business district—the "Loop," as it is called. What this means is that Chicago is probably the only city whose business district is relatively free of unwieldy trucks and delivery wagons.

The Chicago tunnels were, after several years of construction and financial difficulties, finally opened for operation in 1912. From this period on for several years the building of subway systems suffered a setback—due, no doubt, to the fact that the World War upset the financial calculations of many American cities and in Europe the war itself was being fought in the cities where subways were planned.

MADRID

One short route, which had been under construction before the war began, opened in the capital of one of the neutral countries in 1919. This was the two and a half mile line in Madrid. It is a strongly built subway, and one of the deepest in the world. The depth of its subway has served Madrid well during the horrible bombings of civilians which have taken place during the civil war. All Madrilenos who are near the subway when the alarm of a bombing raid is sounded dive for its deep tunnels, where they are safe from the air attacks.



The Madrid subway has not had trains running in it for many months now. Instead, citizens of Madrid take refuge in the deep stations when the Fascists bomb their city. Many whose homes are destroyed just stay in the subway until they can find other places to go. (Pix photos.)



BARCELONA

Barcelona has a short subway which was opened for operation about the same time. This subway uses immense single cars which hold over 300 passengers, instead of a string of smaller cars. It, too, has proved of value to citizens who rush to escape in its depths the merciless bombings of fascist airplanes.

TOKIO

After the World War other big cities began to think of building their long-planned subways. The first actually to get into operation was in Tokio, where the first section of five miles was opened in 1927. There are eight subway routes now under construction in Tokio.

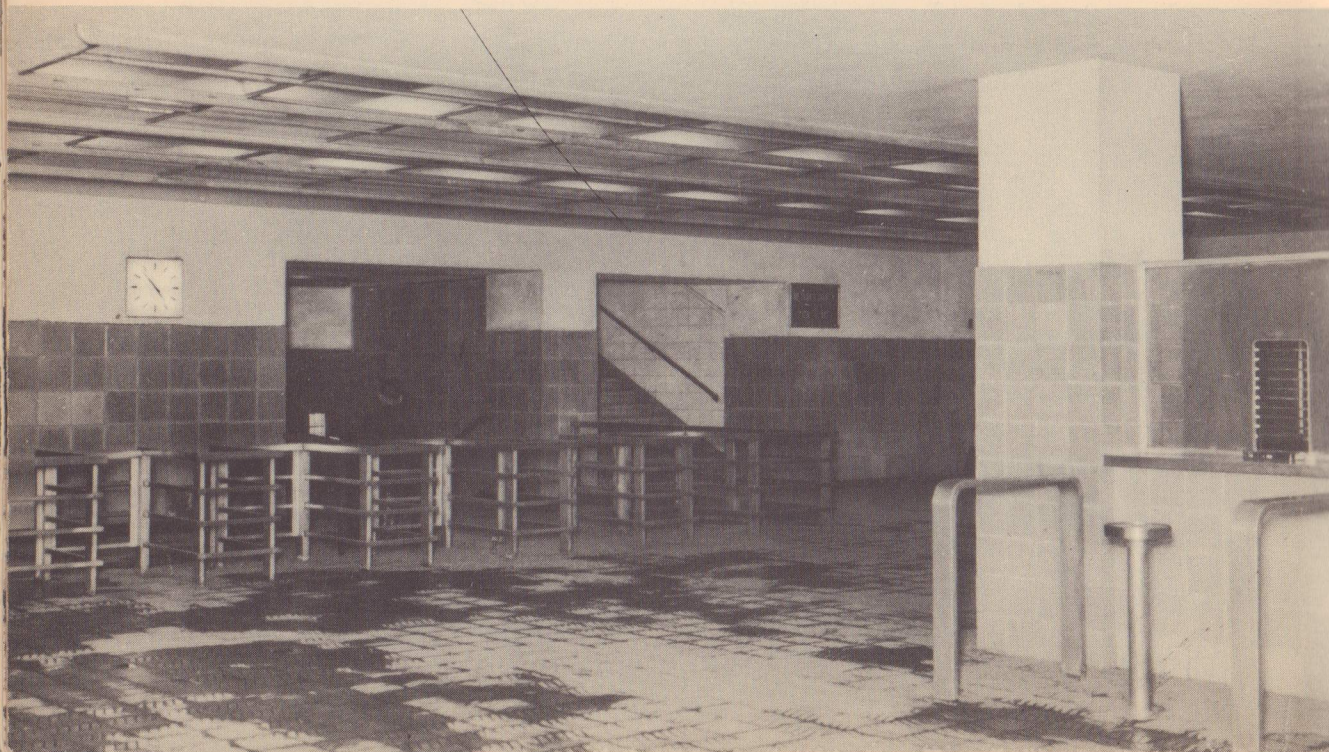
The Tokio subway is a highly modern tube, with all the safety devices one finds in the newest New York or London subways. Like London, this Japanese city has paid considerable attention to the beauty of the stations, the walls of which are lined with highly polished white stone blocks with mirrors inserted in them at frequent intervals.

BUENOS AIRES

One of the simplest underground railways to build was South America's first subway, in Buenos Aires. Parts of the route were built through a peculiar kind of earth which had something of the same consistency as clay. It was so firm and so strongly packed together that the engi-



Working at night on the Tokio subway. Here they are building decking, under which excavation will go on. They shut the traffic off entirely at night while the work is going on. (Courtesy of "The Engineering News Record.") Below—The inside of a Tokio subway station. Note the modernistic lighting in the ceiling. (Courtesy of the Japanese Consulate.)

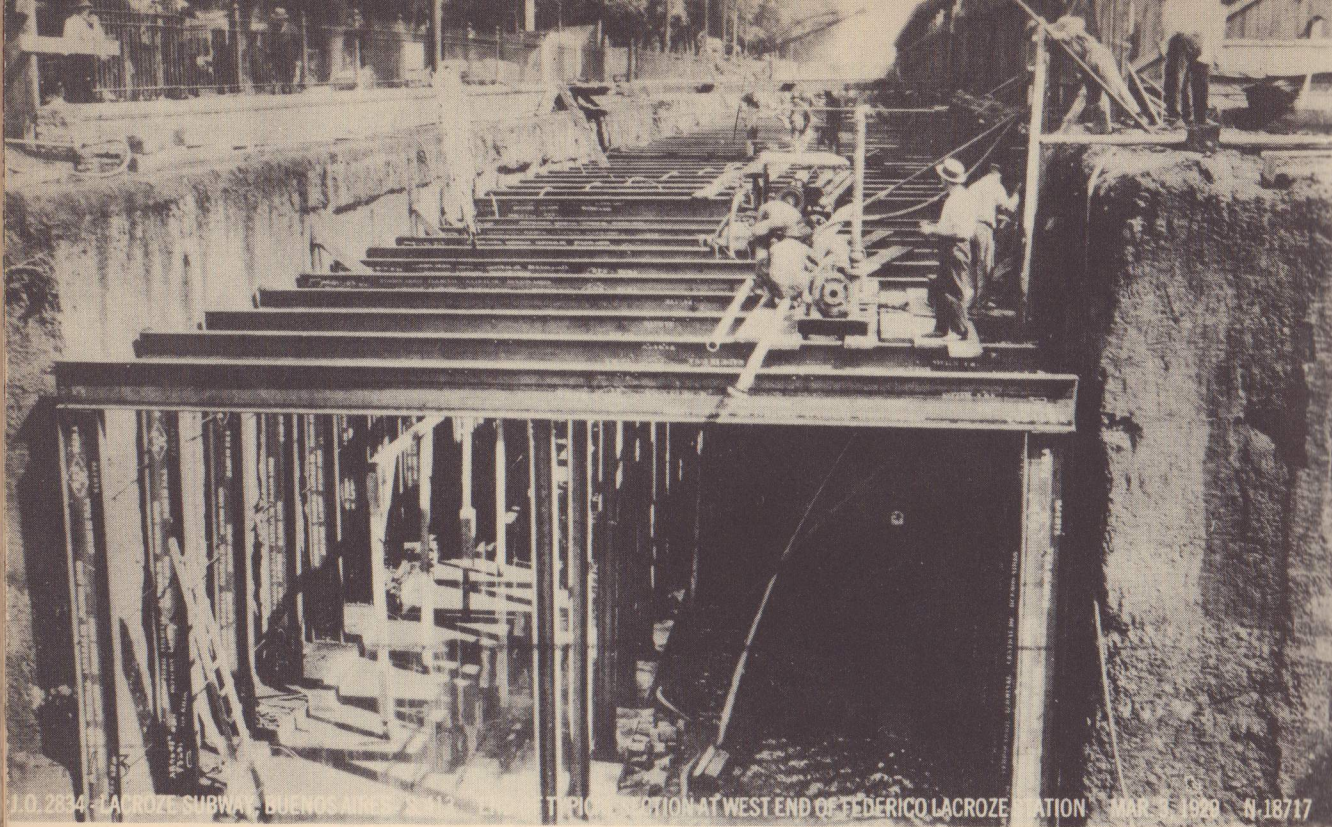


neers were able to excavate clear down to subgrade without having to put up any shoring or side-wall sheet piling whatsoever! They just kept on digging until they reached the bottom and then built the subway structure. No decking was required because the streets were so wide. Because it was such a simple job to do, a four-and-a-half-mile section was completed in twenty-one months—a little less than two years. This was the world's record for speed until the amazing Moscow subway, which we will describe later, was built. Part of Buenos Aires' subway was opened for operation in 1928.

SYDNEY, OSAKA AND OTHERS

In 1932 a three-mile subway for interurban trains was opened in Sydney, Australia, after many years of construction difficulties and other setbacks. And in 1933 a two-and-a-half-mile line was opened in Osaka, Japan. Plans in both cases, as indeed in the case of practically every subway system in existence, have been made for expansion and lengthening of the lines, but financial and other difficulties make it hard for small cities to continue building.

Other tiny subways, mostly ranging from one to two miles in length, have been built in Oslo, Norway; Athens, Greece; Newark, New Jersey; and Rochester, New York. The latter two systems were laid in the beds of abandoned canals. All four of these systems are used only to take surface trolley cars off the busiest streets in town, however, and are not really subways, with special trains of their own.



An excellent view of the simple method of excavation in Buenos Aires. There are no shoring, no piles, no side-wall supports; the earth is so firm that they just go ahead and dig, and then build the subway in the naked hole. (Courtesy of "The Engineering News Record.")

MOSCOW

The last system to be started and the beginning of what will probably be one of the greatest subway systems in the world was started in 1931 in Moscow, U.S.S.R. In many ways the Moscow system is a great engineering marvel and certain features of its construction make it unique among subways.

For two years its construction went on very slowly indeed, for its engineers were experimenting with methods and machinery which had to be developed to fit the special conditions found there. Less than ten per cent of the work had been done by the end of 1933. But at the beginning of 1934 a radical change in the rate of construction set in when thousands of Moscow citizens began donating their free days to dig the subway and the subway workers themselves became more familiar with their job. And in just about a year six miles of the route were completed and ready for operation—a record for speed which has never been remotely approached by any other subway building in the world. The Moscow citizens justly and proudly refer to their subway as “our subway”!

Over 75,000 were working on the *Metro* in Moscow at one time. They worked so fast that the first section was opened to passengers on May 15, 1935. Moreover, as soon as the first section was finished, a second was started.

Of note in the building of this second line is the extraordinary development in use of mechanical equipment which the builders of the subway have brought about. The average subway job, when it employs shields at all, uses at most two. On the new construction job in Moscow



Inside and outside the new Moscow subway. The width of the station platform (above) shows good planning—it means that crowds can always be accommodated. Below is a view of one of the handsome subway station entrances. (Courtesy of "Intourist.")



forty shields are being used—all except the first one of them having been designed and manufactured in the U.S.S.R.

Moscow's subways are all to be built by the shield method, which is made necessary by the incredibly bad ground conditions found there. Practically every type of difficulty ever encountered in tunnel or cut-and-cover construction was found during the building of that first link and the same is proving true of the new sections.

But, with the combination of the most expert use of machinery, the enthusiastic assistance of the citizenry, and the absence of any question about profits—for the subway belongs to the people—Moscow is going to have eighteen miles of first-rate modern subway actually in use by 1939—eighteen miles built and opened for passengers in five years! And before they are finished with subway building in that city, they will have over fifty miles of well-planned and well-built underground railways.

SUBWAYS OF THE FUTURE

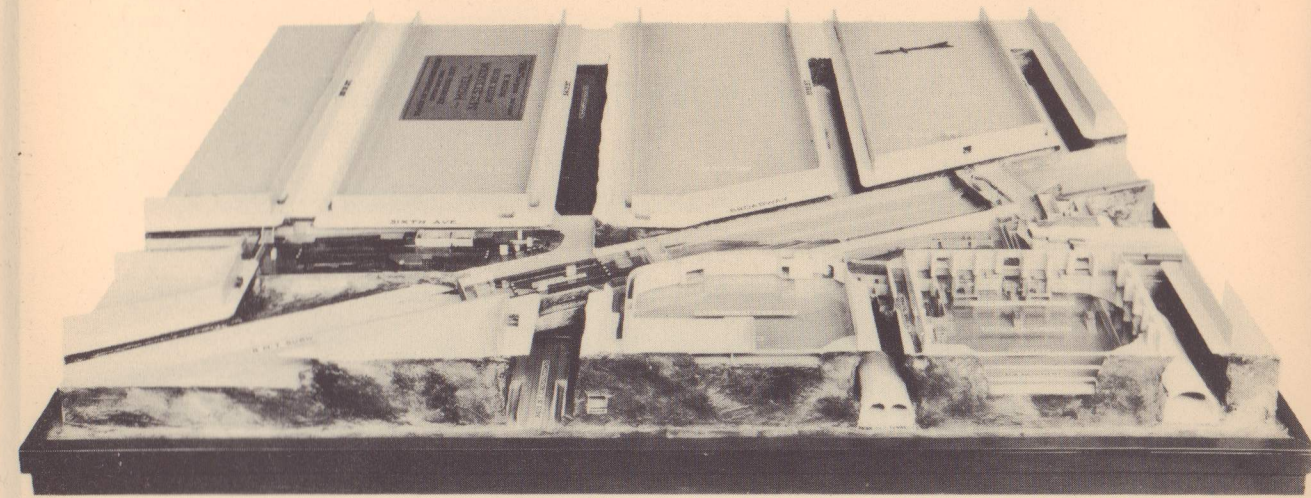
We have told you about the subways of the world, as the world now stands. But it does not stand still, and everywhere more subways are being planned. Rome has started a subway system. It looks as if Chicago might really get down to earth and build one, too. Santiago, Chile, is thinking about it. And as soon as Moscow's subways are well underway, Leningrad will be the next scene of action in the U. S. S. R. That, by the way, will be one of the most difficult systems in the world to build, for Leningrad is practically "built on water." Milan, Italy, is already constructing a short subway, and Vienna was planning to build one before Germany took over Austria. Reports are flying about that



This young woman is not just a conductor in the Moscow subway. She is a train-master, and has charge of the whole train. She is standing in the motorman's booth. (Sovfoto.)

such cities as San Francisco, Detroit, Cleveland, and Cincinnati will be starting to build subways soon. Of course, they have not begun yet, but before many years they all will be having safe, comfortable, swift underground railways.

For the subway has definitely arrived!



Here is a model of the most difficult piece of subway construction which has ever been attempted. The Sixth Avenue Subway has to go over the Pennsylvania Railroad tubes, the Long Island Railroad tubes, and the projected 34th Street crosstown vehicular tunnel, and under the Broadway B.M.T. subway and the Hudson and Manhattan tubes. In addition the elevated railway along Sixth Avenue goes overhead and must be supported, and all the extremely heavy street traffic has to be taken care of. There are mezzanine platforms, crossovers, special ramps, and so on—and to cap the climax, one of the huge high-pressure water mains which bring water down from the Catskills to service New York's millions lies 200 feet under the street level, and exceptional care must be taken not to disturb that deep-lying main by blasts or by digging too low and thus unsettling the tunnel through which the water goes.

THE SUBWAY SYSTEMS OF THE WORLD

This table includes only passenger subway systems. It omits listing underground sections of railways which are mostly surface lines, such as in Oslo, Athens, Newark, N. J., and Rochester, N. Y.; and it leaves out the Chicago system, which is for freight only.

Year first link of system was opened to traffic	City	Route mileage, of tunnels, exclusive of surface or "El" lines*
1863	London	79
1886	Glasgow	16
1896	Budapest	2½
1898	Boston	23
1900	Paris	70
1902	Berlin	39
1904	New York	133**
1908	Philadelphia	10½
1919	Madrid	2½
1920	Barcelona	4
1927	Tokio	5
1928	Buenos Aires	10
1932	Sydney	3
1933	Osaka	2½
1935	Moscow	18

*Route mileage is the number of miles of subway *structure* a city contains, as opposed to track mileage, the number of miles of track in those structures. Track mileage is at least twice as much as route mileage in most cases.

** The Independent System, 57 miles; the B. M. T., 31½ miles; the I. R. T., 44½ miles.

HOOD AVIATION

YRABDI VTRUOO

