Network Construction

Network construction comprises the following steps:
1 site preparation,
2 excavation,
3 trench dewatering,
4 pipe laying,
5 jointing,
6 backfilling,
7 testing & disinfection.

After the site has been prepared, all the other steps are conducted simultaneously at various sections of the pipe route; at its end, the pipes are tested; a few pipes further, the backfilling takes place; and at the same time at the preceding section the pipes are jointed, etc. This coordinated method of working is important in order to shorten the total duration of the construction, reducing both the cost and disturbance. The laying of a few sections of steel pipe is shown in Figure 5.1.

Pipes can also be laid above ground or in tunnels, which then require adapted laying techniques such as the use of casings, anchorages and supports, etc. Some typical principles and solutions are briefly presented in this chapter.

Figure 5.1. Laying of steel pipe.
5.1 SITE PREPARATION

Pipes can be laid only when the route is completely clear. Site preparation in urban areas can be a complex task where cooperation with other utilities is very important. Works on water, electricity, gas, road or other infrastructure are often carried out simultaneously.

Before the work can commence, mutual agreement should be obtained about the working area so that other daily activities are not significantly affected during the construction. Proper signalling, footpaths and crossings for pedestrians, signs and warnings, a restricted access to the equipment in operation etc. must be provided during the entire period of work.

Pipes will be tested prior to leaving the factory and should also be tested after reaching the site in order to check for possible damage resulting from transportation. Further damage to the pipe is possible during the process of unloading, stacking and/or stringing along the laying route. The dropping of pipes, pipes striking each other, bundling pipes too high and stacking them on an uneven surface or without proper support will all have a negative effect. Each scratch on the external or internal coating of a metal pipe is a potential source of corrosion. Cement-based pipes are very vulnerable to impact damage and plastic pipes, although lighter, are not an exception in this respect; scratches on PVC reduce the pipe strength. Hence, a final check is necessary for each pipe before it is put into position.

Pipes and fittings waiting to be installed should be kept clean in a fenced storage as a protection against potential theft and vandalism (Figure 5.2).

Before excavating paved surfaces and roads, the cutting of edges of the trench has to be done to avoid damage to surrounding areas. If traffic

![Figure 5.2. Pipe storage on the construction site.](image-url)
loads allow, the pipe route will be located alongside the road, preferably not too far from it, which reduces damage to the pavement resulting from excavation. Breaking the surface is usually carried out by pneumatic hammers. Large pieces of concrete and asphalt will be removed from the site as they will not be used for backfilling. If the surface is not paved, the topsoil is usually removed by scrapers and stacked for use in the final reinstatement of the site.

5.1.1 Excavation

Excavation is the most expensive part of pipe laying. The choices of technique and trench dimensions are therefore very important factors that will affect the total cost. The preferred excavation method depends on
- available space on the site,
- soil conditions,
- width and depth of the trench.

Excavation is commonly carried out by mechanical excavators (Figure 5.3). In areas where there are obstructions (e.g. other services are in the trench) or access for the machine is restricted (small streets, busy traffic, etc), excavation by hand might be required (Figure 5.4). For smaller trenches (up to 300 mm wide and 1 m deep) vacuum excavation can be used. After breaking the surface and removing the top layer in the conventional manner, a special pneumatic digging tool is used. With this method, the soil is then removed through a flexible hose.

Care has to be taken during the work:
- to stabilise the walls, either by battering or shoring,
- to clear the trench edges of chunks of rock or earth that could potentially damage the pipe or hurt the workers,
- to leave enough space between the trench and pile of excavated material,
- to keep the work as dry as possible.

Figure 5.3. Mechanical excavation in sand.
Batter-sided trenches are rarely used in urban areas because of the space needed. Where possible, the angle of slope should depend on the trench depth and soil characteristics, as shown in Figure 5.5. Different techniques of shoring can be applied by (Brandon, 1984):

1. prefabricated wooden panels (jointed or single),
2. wooden or metal sheets,
3. pile driven sheets.

The choice of technique, dependant on the soil conditions, is often prescribed by laying regulations. Three groups of soils can be distinguished regarding their suitability for excavation (see Figure 5.6).
Rocks are extremely cohesive materials but the possibility of collapse cannot be excluded. Cracks are sometimes present, which can result in rocks falling. Excavation is difficult in this type of soil.

 Friable soils are the most common soils. A certain degree of cohesion allows them to hold together for a while during excavation. However, these soils are very sensitive to water, and collapse of the trench walls caused by the vibration of the equipment is also possible.

 Non-cohesive soils are soils without any cohesion (e.g. dry sand, mud or freshly restored backfill), which collapse almost instantly. Protection against the danger of collapse is therefore essential.

Shielding The shielding technique can be used in rocky and friable soils, in the absence of shoring. By this method, the laying and jointing work takes place in a partly open steel box that is pulled throughout the trench as the work progresses. The sidewalls of the box do not prevent occasional caving in of the soil, as the width of the box is smaller than the trench width in order to be able to pull it smoothly. The main objective here with this method is the protection of the workers.

How much trench is excavated depends on the time necessary for pipe laying and backfilling. Normally, the trenching is excavated a day or two ahead of the pipe laying, depending on the laying methods applied. However this should not be carried out too far in advance, as empty trenches may accumulate rainwater and are potentially dangerous, especially outside working hours.

The width of the trench at the bottom depends on the pipe diameter. An additional space of 0.3–0.6 m around the pipe (external diameter) should be provided for shoring and jointing works.

Extreme temperatures can have an impact on the operation of water distribution systems, not only by affecting the water consumption but also by causing pipe damage either by freezing or very high temperatures. While deciding on the optimal trench depth, care should be taken to minimise the temperature impact on pipes and joints. On the other
hand, increasing the depth beyond what is really essential is more costly, not only during installation but also in the maintenance phase. Some degree of pipe burst under extreme weather conditions is always acceptable if the repair can be conducted quickly and without disturbance to a large number of consumers.

In general, the minimum cover over the pipe crown in moderate climates are

- 1.0 m for transmission lines,
- 0.8 m for distribution pipes,
- 0.6 m for service pipes.

For frost prevention, pipes are laid deeper in areas with a cold climate, sometimes up to 2.5–3 m, which depends on the degree of frost penetration in the ground. Alternatively, pipes in shallow trenches can be laid with thermal insulation. In extremely hot climates, the pipes will also be buried deeper, mainly to preserve the water temperature. Examples from practice are shown in Table 5.1.

The excavated material is deposited alongside the trench if it is going to be used for backfilling. Its location should not be too far from the trench but also not too close, as it exerts pressure on the trench wall, risking its collapse. Moreover, it also limits the movement of the workers. In general, approximately 0.5 m space should be left free for deposited material.

**Tunnelling**

Excavation for laying pipes passing under roads, railways and watercourses is done by tunnelling. The special reason for this is to protect the surrounding area from erosion caused by the pipe burst or leakage, which can have catastrophic consequences. Second, the pipe is protected in this way from soil subsidence and vibrations caused by traffic, and maintenance can be carried out without interruptions or breaking of the surface.

Excavation of tunnels is a very expensive activity. In this situation thrust boring is applied, whereby a rotating auger moving the excavated material backward pushes a steel shield pipe forward. New lengths of pipes are welded or jointed together as the tunnelling proceeds, finally appearing at the other side of the crossing.

**Cut and cover method**

The thrust boring technique is successful for short lengths of tunnels, up to 100 m, and for pipes of maximum 2500 mm diameter (Brandon, 1984).
For longer lengths and larger diameters, a tunnel should be constructed by traditional methods. These structures can also serve to accommodate several pipes, usually water mains carrying large quantities of water. In rock, the tunnel section can be a vertical wall lined with concrete; for other soils circular sections formed by reinforced concrete segments are common. When the tunnel is shallow it can be constructed by the cut and cover method and in this situation a reinforced concrete box culvert is a more suitable solution.

5.1.2 Trench dewatering

The normal method of removing water as it enters the excavation is by pumping (Figure 5.7). Sand and silt in unstable soils are mixed with water and carried out as well. If this continues over a period of time, there is a danger of subsidence in adjacent ground. In such situations, the removal of ground water can be carried out by using well point dewatering equipment (Figure 5.8). The water is collected through perforated suction pipes put in the ground below the lowest excavation level. All suction pipes are connected to the header pipe, which transports the water by vacuum created by a well point pump. The equipment used for this method is shown in Figure 5.9.
Although proven to be very efficient in the case of non-cohesive soils, the well point dewatering method can rarely be used in impervious soils because the water is not able to flow to the extraction points. Electro-osmosis, forcing the water by means of a passage of electrical current to a dewatering point, may be successful in maintaining vertical sides in wet unstable silt.

5.2 PIPE LAYING

5.2.1 Laying in trenches

The trench bottom provides the pipe’s foundations. In homogeneous, even and well-consolidated soils, pipes can be laid directly on the bottom. The pipe should touch the ground surface with its entire length. To facilitate this, the space around joints should also be excavated. In rocky soils, a pipe bed of 15–20 cm should be provided (Figure 5.10). Depending on the pipe material, the bed can be made of sand, gravel or dry concrete, which assumes that the surface of the trench bottom is even and well compacted.

When it is necessary to lay on less stable ground, pipes should be supported on piles based on a stable material, if such materials is to be found at a depth less than 1.5 m. Care should be taken to avoid point loads being transmitted to the pipes (particularly in the case of PVC pipes).
Piles can also provide support to the pipes in waterlogged grounds. If this is not sufficient, lowering the ground water table can be achieved by laying a drain alongside the trench at a depth of 0.5 m below the pipe invert. The pipe is bedded on the reinforced concrete raft placed across the trench bottom, which ensures its stability. An example of concrete transportation pipes laid on wooden piles is shown in Figure 5.11.

Most pipes are still laid individually in the trench. With the increased use of flexible pipes, the technique of laying large sections of distribution mains is becoming more common. The placing of pipes on the prepared bed in a position ready for jointing requires appropriate equipment and skill (Figures 5.12 and 5.13). The precise laying procedure depends on the

Figure 5.11. Pipes laid on wooden piles.

Figure 5.12. Testing of external coating.
pipe material; the advice of pipe manufacturers must be taken into account here. The entering of ground- or rainwater into the pipeline is highly undesirable, so pipe stoppers should be used if the work has to be halted, for example, at the end of the day. In highly corrosive ground, metal pipes (and joints) can be sleeved into a polyethylene film at the time of laying as an additional protection to the external coating, as shown in Figure 5.14.

5.2.2 Casings

Different principles of casings are possible; two methods are shown in Figures 5.15 and 5.16.

Old pipes can sometimes be used as casings for the new pipes (Figure 5.17). This solution will probably reduce the maximum capacity of the line, although the smaller diameter is partly compensated for by the decreased roughness values of the new pipe. Special care should be paid to the jointing of the new pipes in order to make the route leakage free, as there is little space for any possible future repairs or maintenance.

5.2.3 Laying above ground

The following aspects should be considered when laying pipes above ground:
1 the design of the support system,
2 the accommodation of thermal expansion,
3 the anchorage of components subjected to hydraulic thrust,
4 protection against freezing (where necessary).
Figure 5.14. Protection of pipes and joints (Pont-a-Mousson, 1992).
Some examples of the laying of DI pipes in tunnels and crossings are shown in Figures 5.18–5.20.
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Clamps
(Fixed points)

Fixing clamp
Rubber lining

Joints
(Expansion accommodation)

Concrete support

Clamp

Anchored joints

Figure 5.17. Casing of a PE pipe in an old CI pipe.

Figure 5.18. Pipe laying on a concrete support (Pont-a-Mousson, 1992).
Figure 5.19. Pipe laying at a crossing (Pont-a-Mousson, 1992).

Figure 5.20. Pipe laying when crossing a road (Pont-a-Mousson, 1992).
5.3 PIPE JOINTING

Examples of jointing principles and tools are shown in Figures 5.21–5.24.

5.3.1 Flanged joints

Figure 5.21. Pipe jointing using flanged joints.

5.3.2 Gland joints

Figure 5.22. Pipe jointing using gland joints.
5.3.3 ‘Push-in’ joints

Figure 5.23. Pipe jointing using ‘push-in’ joints.

Figure 5.24. Jointing equipment (Pont-a-Mousson, 1992).

5.3.4 Anchorages and supports

After the pipes have been laid and connected, the concrete anchorage and support structures must be cast before backfilling is completed. Anchor blocks are designed depending on the pipe configuration and soil characteristics. In principle, each case is considered separately (Figure 5.25). The design takes into account the forces involved and the result is usually expressed as a volume of concrete required to carry the thrust. The water pressure taken into consideration for this calculation is the maximum anticipated one, with an additional safety factor in case pressure surges are expected.

Concrete should be placed and consolidated against undisturbed soil and around the pipe or fitting to achieve a good bond. Care must be taken when filling with concrete to keep joints clean. The position of the thrust blocks for some typical bends and junctions is shown in Figure 5.26.
Figure 5.25. Anchorage of pipe bends.

Figure 5.26. Thrust blocks in distribution systems (AWWA, 2003).
5.3.5 Backfilling

Backfilling of the trench can be done in two phases: partly, immediately after pipe laying to prevent floating caused by sudden heavy showers, and finally, after completion of the hydraulic tests. Two general layers can be distinguished (Figure 5.27):
1. pipe surround (initial backfill),
2. main backfill (infill).

The surround provides stability and protection for the pipe and increases the bearing capacity for external loads. The type of material used depends on the pipe characteristics and soil conditions. The infill varies according to the area involved and stability of the surface.

Fine material should always be used for the initial backfill; excavated sub-soil may also be suitable. Stones, rocks and any sharp materials are not allowed close to the pipe. The soil is normally placed in the trench in layers of 15–20 cm, and each layer is well compacted by machines that do not damage the pipe. The pipe can also be partly surrounded by the initial backfill but this reduces its supporting strength to a large extent; Table 5.2 illustrates this.

Top backfill in urban areas usually has to follow specifications required by road authorities, in open areas it is more related to aesthetics.

5.3.6 Testing and disinfection

As soon as the pipe laying is completed, a hydraulic test has to be carried out to check the quality of workmanship, namely
- the mechanical strength and leak tightness of the system,
- the strength of the anchorage and support structures.
All changes of directions, fittings and valves should be permanently anchored before the test starts. The ends of the tested section must be securely closed and temporarily anchored as well. There must be sufficient backfilling to prevent movement of the pipes during the test, but the joints should be left exposed until testing has been completed (Figure 5.28).

Water mains can be tested in lengths varying from a few hundred metres up to about a kilometre; although possible in theory, in practice it is more difficult to detect leaks with distances of more than 500 m. Pending good initial results, the length of the sections that are tested can be increased as the work progresses. The test pressure applied depends on the regulations. For distribution systems, it is usually 50% higher than the maximum working pressure. A common method, shown in Figure 5.29, is described in detail below.

The test starts by filling the section with chlorinated water, if possible from the lower of the two pipe ends. It is essential to ensure that the main has been completely purged of air before it is pressurised.

After filling, the section should be left under moderate pressure until stable conditions are achieved. The length of this period depends on the quantity of air trapped and the absorption of pipe material. For absorbent pipes such as AC and concrete, or cement-lined pipes, it can take a couple of days before the pipe material is fully saturated.

The pressure is then brought up to the test value by a hand-operated pump and all exposed parts of the section are examined for water tightness. The duration of the test and interpretation of the results depend on regulations. According to the French standards, the test is successful if the pressure in the section does not drop more than 2 mwc within 30 minutes (Pont-a-Mousson, 1992). By British standards, a leakage level in the section is monitored through the amounts of water pumped to re-establish the testing pressure after the drop. A tolerable leakage is 0.1 l/d per km of section and per mm of pipe diameter, under 30 mwc of pressure (Brandon, 1984).

If the limits are exceeded, a systematic search for leaks must be made. If standard methods of leak detection do not produce a result, the testing has to be repeated on shorter sections in order to isolate the

<table>
<thead>
<tr>
<th>Degree of initial backfill</th>
<th>Increase in load-bearing strength (%)</th>
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<tbody>
<tr>
<td>No initial backfill</td>
<td>–</td>
</tr>
<tr>
<td>Backfill up to 50% of horizontal diameter</td>
<td>36</td>
</tr>
<tr>
<td>Backfill up to 60% of horizontal diameter</td>
<td>73</td>
</tr>
<tr>
<td>Backfill up to full diameter (half pipe)</td>
<td>114</td>
</tr>
<tr>
<td>Backfill covering entire pipe (Figure 5.27)</td>
<td>150</td>
</tr>
</tbody>
</table>

Table 5.2 Load-bearing strength of rigid pipes (AWWA, 2003).
leakage points. On rare occasions air pressure testing can be used for locating defective joints in waterlogged conditions.

When the hydraulic test has been successfully completed, the pipeline should be flushed out to remove any remaining debris and properly disinfected. The British regulations prescribe a chlorine disinfection applied in a dose sufficient to maintain a residual of 20–30 mg/l, which must stand for at least 16 hours. Before being washed out, the water in the pipeline must be de-chlorinated. After washing out, the network can be charged by water, and after testing of the water quality, it can be put into service.