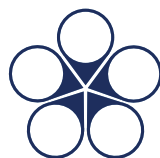




CPAA DESIGN MANUAL

Jacking Design Guidelines

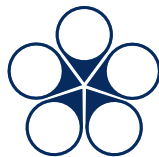


Concrete Pipe Association
of Australasia

Jacking Design Guidelines

First edition 1990

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**Concrete Pipe Association
of Australasia**

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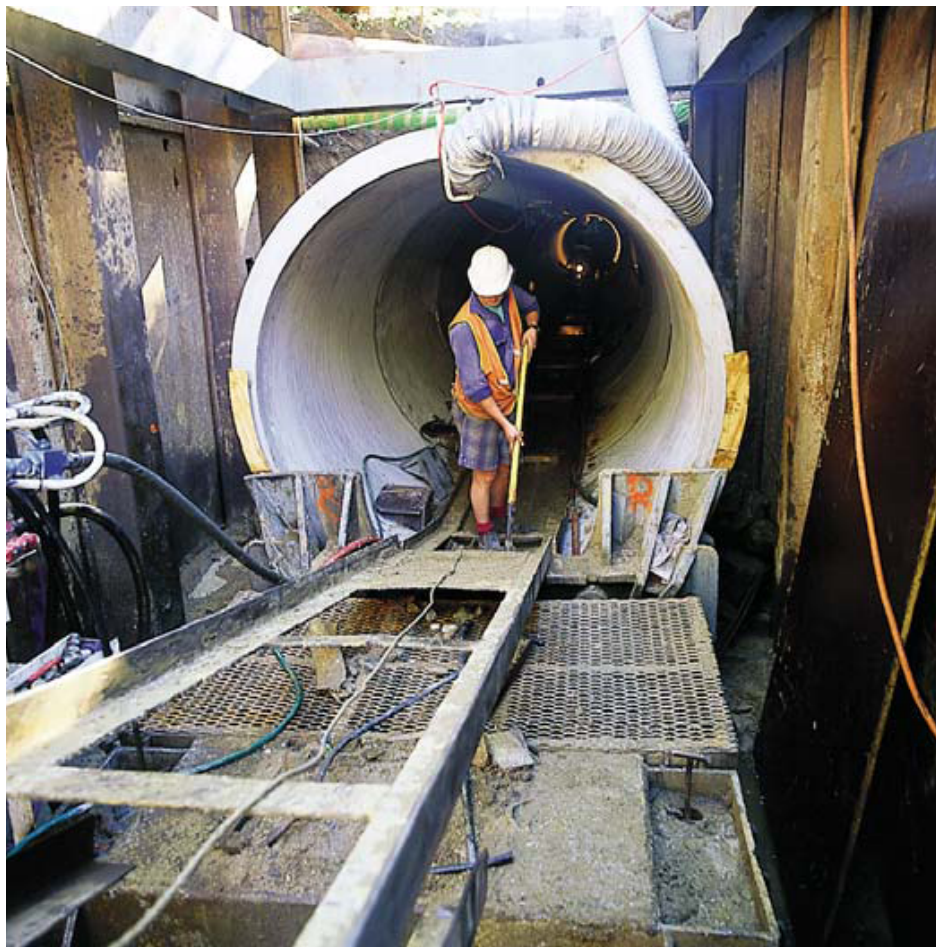
7. REFERENCES

1. Introduction

Installation by jacking is a technique applicable to pipes of concrete and other rigid materials. Its use has become increasingly common in locations where open trenches would seriously interfere with existing installations or with the traffic.

The pipes are positioned one by one in a pit or pits excavated at intervals along the line, and from here the pipes are driven through the ground by hydraulic jacks. The excavation is carried out at the first pipe, which is equipped with a shield, and - from here the spoil is carried back to the jacking pit for disposal. The procedure is shown diagrammatically in Fig. 1.1.

Since this construction method was first introduced in the USA at the end of last century the technique has become generally accepted throughout the world and considerable development of plant and procedures has taken place, particularly in the last two decades.



2. Scope

Pipes have been jacked in diameters up to 4000 mm with the most common range 900 to 1800. Short lengths of smaller diameters have been jacked through holes that have been either predrilled or thrust bored, or the pipes have been forced through the ground and the spoil removed with an auger.

The desire in recent years to jack long lengths of 800 and smaller has lead to the development of very elaborate excavation, control and jacking equipment with excavation, spoil removal, grade and bearing control all performed by remote control.

Locations where jacking is most commonly used is under roads, railways, waterways or developed areas where excavation would cause major disruption.

Length of pipe strings jacked range up to at least 250 m and longer lengths are readily achievable with intermediate jacking stations, but most economical range appears to be 100-120 m.

Jacking forces usually range between 1200 and 7000 kN but up to 30,000 kN have been used.

Whilst jacking in straight lines of even grade is the most common, horizontal as well as vertical curves have also been jacked.

The ground best suited for pipeline construction through jacking consists of granular or cohesive soils. Quicksand and swampy (peaty) ground is poorly suited as control of line and grade is extremely difficult, and jacking through rock requires special excavation equipment or the use of explosives.

3. Jacking Pipes

3.1 The Forces Involved

Jacking pipes, as opposed to pipes laid in open excavations, are subjected to both jacking forces and external earth loads and both of these have to be considered when specifying the pipes.

The effect of the jacking force on the pipe barrel is mostly small on account of the high compressive strength of the concrete. The joint, however, must be considered because the joint cross-section is smaller, as a rule, than that of the barrel and the jacking force is transferred eccentrically across the joint.

The external earth load on the barrel is equal to or smaller than the trench load on a pipe bedded in a trench of same width as the excavation (i.e. the outside diameter of the pipe plus a margin for over-excavation).

The jacking method of installation, therefore, is very efficient from an external load point of view since the external earth load is smaller than both trench and embankment load on pipes of the same diameter under the same height of fill.

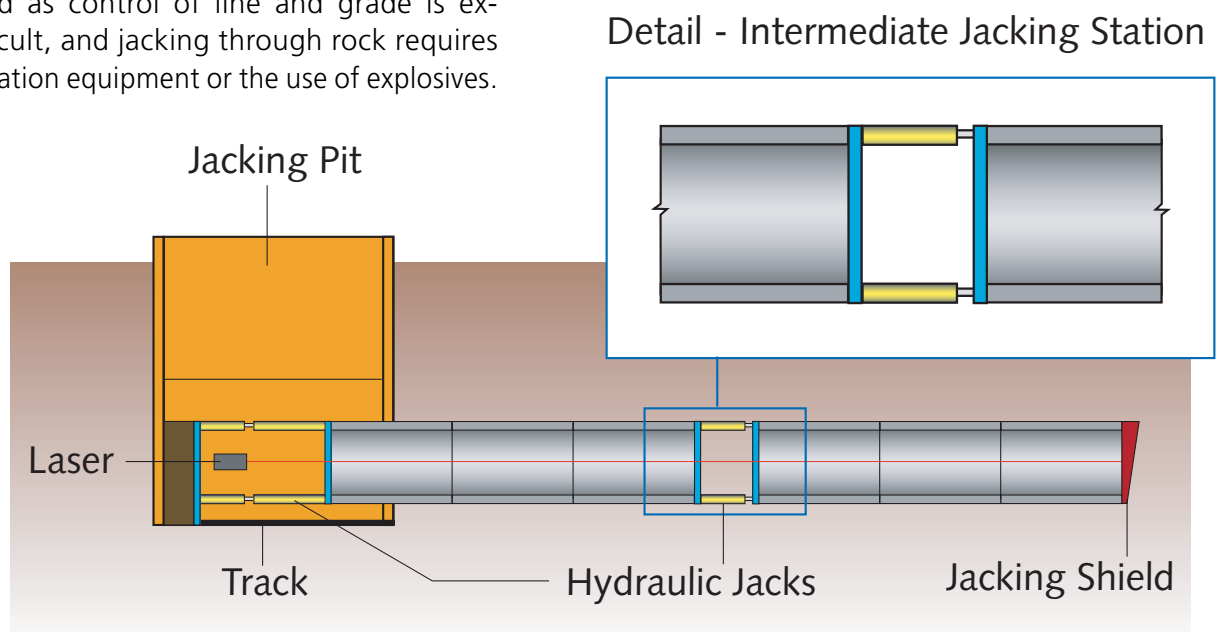


Figure 1.1 Typical Jacking Arrangement

3.2 Barrel Design

Experience has shown that it can be difficult to control rotation of the pipes during the jacking operation. For this reason it is customary to specify circular reinforcement for jacking pipes.

The earth load W_e on the pipes is calculated from the following formula:

$$W_e = C_t w B^2 - 2c C_t B \text{ where}$$

B is the maximum width of the excavation

w is the unit weight of the soil above the pipe

c is the soil cohesion for which indicative values are given in Table 3.1

C_t is the trench load coefficient graphed in Fig. 3.1

| Type of Soil | | Values of c kPa |
|--------------|-----------|-------------------|
| CLAY | SOFT | 2 |
| | MEDIUM | 15 |
| | HARD | 50 |
| SAND | LOOSE | 0 |
| | SILTY | 5 |
| | DENSE | 15 |
| TOP SOIL | SATURATED | 5 |

Table 3.1 - Soil Cohesion (c)

Minimum Test Load

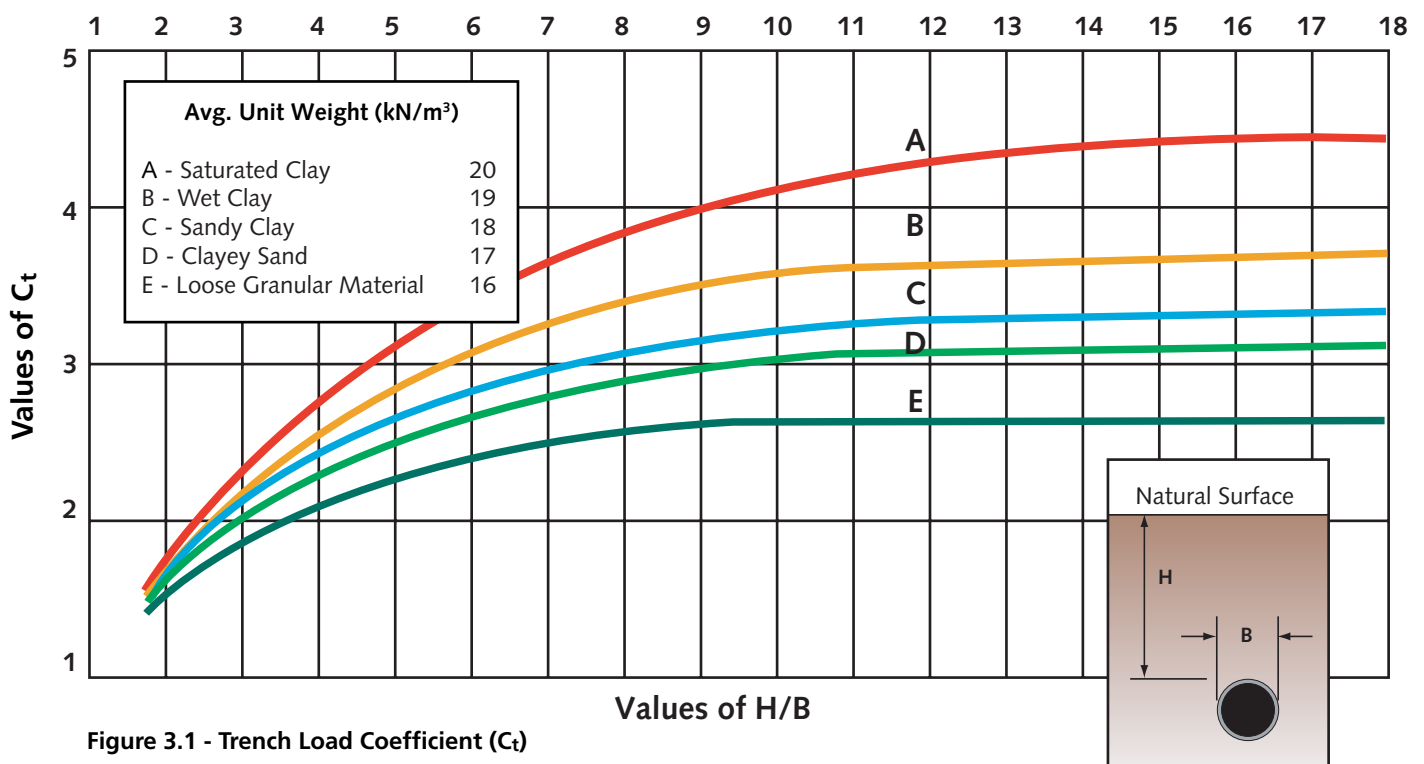
(see Australian Standard AS/NZS 4058-2007)

The minimum test load (T.L.) required is:

$$T.L. = \frac{W_e}{F}$$

F is a factor which can be assumed to be between 2 and 3 depending on the degree of over-excavation, with the smaller value corresponding to the larger space between the excavation and the outside of the pipes.

(Refer clause 9.3.3 AS/NZS 3725-2007).



3.3 Joint Design

Many special jacking joints have been developed to cater for various applications. Some typical joints are shown in Fig. 3.2

Normal flush joint pipes have been successfully jacked and are suitable for moderate jacking forces.

A packer must be applied as shown in Fig. 3.2a. It extends over the full length of the periphery, but because the contact area is small in comparison with the wall thickness and the load is eccentric relative to the cross-section the joint is limited to jacking forces of the order given in Table 3.2.

These values do not take into consideration the influence of packer thickness, elasticity and joint deflection, which is dealt with in more detail in Section 6.

Rubber ring joints are included where watertightness is essential which is mainly in sewer and access tunnel applications. Details incorporating concrete sockets as well as stainless steel socket-sleeves have been used. (See Fig. 3.2c-e).

Influencing these details are:

- i) The magnitude of the jacking force.
- ii) The joint deflection required.

Both of these parameters depend on the degree of control exercised over the operation, which again depends on the sophistication of the equipment available.

The ease with which tolerances on line and grade are achieved depends on the squareness of the ends of the pipes as well as the equipment. In this context reference should be made to the relevant clauses on end squareness in Australian Standard AS/NZS 4058-2007.

| Diameter (mm) | Max. Jacking Force (kN) |
|---------------|-------------------------|
| 900 | 1200 |
| 1200 | 1800 |
| 1500 | 2200 |
| 1800 | 3100 |
| 2100 | 7000 |

* Refer to manufacturer for allowable jacking forces for different joint configurations

Table 3.2 Maximum Jacking Forces

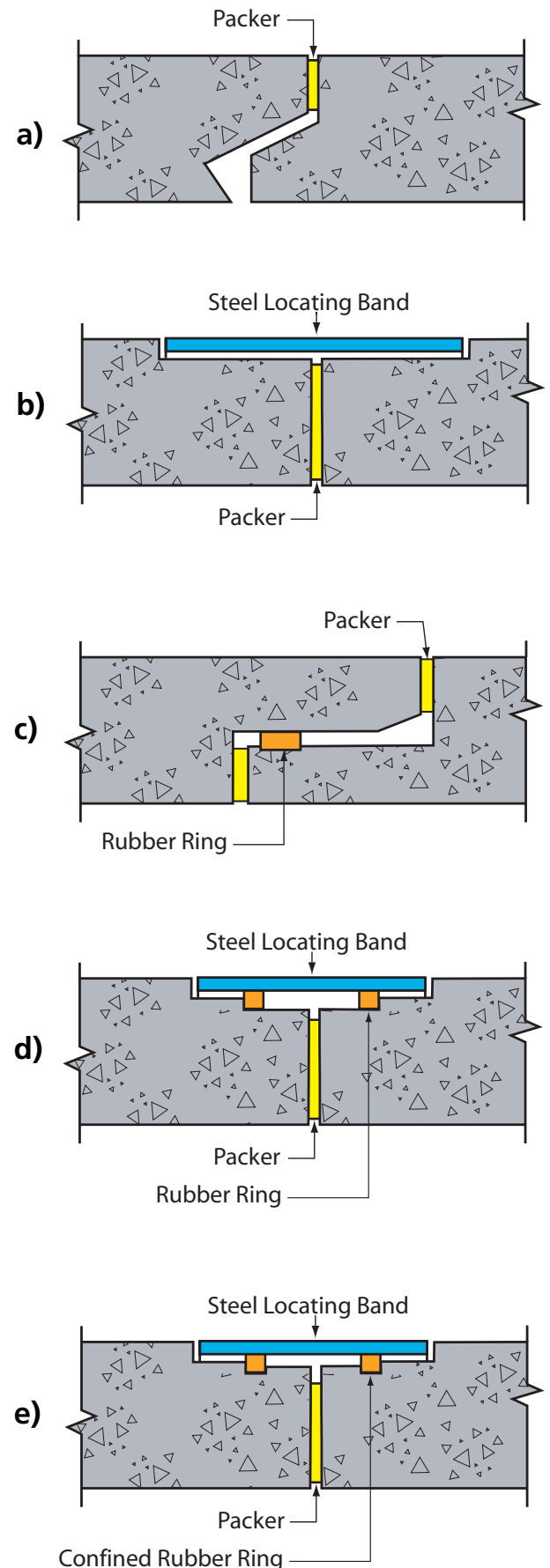


Figure 3.2 Joints Suitable for Jacking Pipes

4. The Jacking Forces

The resistance which has to be overcome during the jacking operation varies considerably from case to case and only a range can be indicated. The influencing factors are:

1. Length and outside diameter of jacked line
2. Weight of pipe
3. Height of overburden
4. Nature of ground
5. Load on shield or leading edge
6. Whether operation is continuous or not
7. Lubrication

When the jacking operation is stopped the resistance builds up very quickly in some soils. Jacking force increases of 20-50% are reported following delays of as little as 8 hours. Under such circumstances pipe jacking should be carried out as a continuous operation whenever possible.

The pipe jacking resistance per unit area of external surface ranges from 5 to over 40 kPa, and typical values for various ground conditions are listed in Table 4.1.

| Ground Condition | Jacking Resistance (kPa) |
|------------------|--------------------------|
| Rock | 2-3 |
| Boulder Clay | 5-18 |
| Firm Clay | 5-20 |
| Wet Clay | 10-15 |
| Silt | 5-20 |
| Dry Loose Sand | 25-45 |

Table 4.1 Jacking Resistance for Various Ground Conditions

Having regard to the high static resistance, jacking capacity to cope with unscheduled stoppages is necessary.

In cohesive soil a substantial portion of the resistance is ground adhesion, and this can be reduced by lubrication. The most commonly used lubricant is Bentonite, which is injected through nipples in the jacking head and along the pipe wall. It is claimed that lubrication repeated every 2-3 days can reduce the jacking force by more than 50% but average reductions of about 30% are more common.

5. Joint Stresses and Deflections

The theoretical line and grade of a jacked pipeline is never completely achieved in practice. Without making any allowance for margins to cover variations in concrete strength, which is irrelevant having regard to the approximate nature of this analysis, a uniform joint stress of around 35/3 to 45/3 MPa or 12 to 15 MPa can be allowed for machine-made and wet-cast pipes respectively.

Such deviations are corrected by adjustments which result in angular deflections at the joints as did the original deviations prompting the adjustments.

In order to avoid damage to the joints due to over-stressing by the jacking force it is of importance to estimate the stress concentrations resulting from the angular joint deflections.

As a first approximation it can be assumed that stress concentrations about 3 times the joint stress resulting from completely uniform application of the jacking force must be expected.

Without making any allowance for margins to cover variations in concrete strength, which is irrelevant having regard to the approximate nature of this analysis, a uniform joint stress of around 35/3 to 45/3 MPa or 12 to 15 MPa can be allowed for machine-made and wet-cast pipes respectively. A more detailed analysis has been carried out by Lenz and Moller (Ref. 18) and the following approach is based on their development.

It is here assumed that the pipes are separated by elastic packers of wood or hardboard. Materials with a high Poisson's ratio like rubber and plastic are not suitable, as they cause spalling of the joint edges

The thickness of these packers before permanent deformation is a' . Packer thickness after permanent deformation, $a = 0.6 a'$.

Pipe length: L

Total packer and pipe deformation can now be written:

$$\Sigma \Delta a = \Delta a + \Delta L$$

Where Δ represents the dimensional change.

The deformations can be related to the stresses:

$$\sigma_j \frac{a}{E_j} = \sigma_j \frac{a}{E_p} + \sigma \frac{L}{E_c}$$

where σ_j is the stress in the joint and σ in the wall.

E_p and E_c are the corresponding elasticity coefficients, and E_j an equivalent joint elasticity coefficient taking into consideration pipe wall elasticity.

$$\sigma = \sigma_j \frac{t_j}{t}$$

hence:

$$\sigma_j \frac{a}{E_j} = \sigma_j \frac{a}{E_p} + \sigma_j \frac{t_j}{t} \frac{L}{E_c}$$

and:

$$E_j = \frac{a t E_p E_c}{a t E_c + L t_j E_p}$$

The problem is now reduced to that of the stress distribution in an annular cross-section where the tensile stresses are disregarded.

This case is treated in Ref. 12 and for the ratios of inner to outer radii of the joint $r_i / r = 0.8, 0.9$ and 1.0 curves linking

$\max \sigma_j / \sigma_{j0}$ and $\frac{\max \sigma_j / \sigma_{j0}}{z/r}$ are shown in Fig. 5.1.

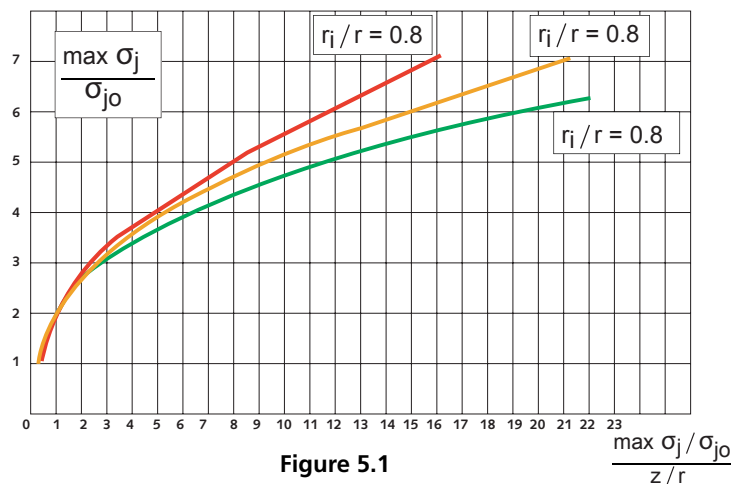
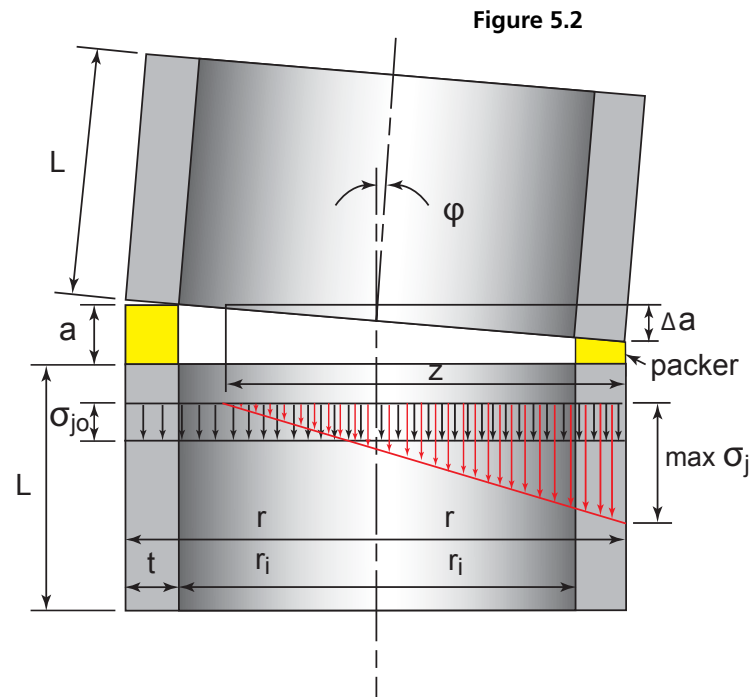


Figure 5.1



In these expressions σ_{j0} is the joint stress for uniform load.

From Fig 5.2 follows:

$$\phi \approx \tan \phi = \frac{\Delta a}{z}$$

where:

$$\Delta a = \frac{a \max \sigma_j}{E_j}$$

hence:

$$\phi = \frac{a}{E_j} \frac{\max \sigma_j}{z}$$

or in radians:

$$\phi = \frac{a}{E_j} \frac{\sigma_{j0}}{r} \frac{\max \sigma_j / \sigma_{j0}}{z/r}$$

and degrees:

$$\phi = \frac{180}{\pi} \frac{a}{E_j} \frac{\sigma_{j0}}{r} \frac{\max \sigma_j / \sigma_{j0}}{z/r}$$

This equation allows us to estimate the safe deflection for any pipe-joint configuration. It must be noted that this deflection is the combined pipe-packer deflection and is larger than what would be measured at the joint.

If the deflection concentrated at the joint only is required the value of E_p should be substituted for E_j in the equation for ϕ .

Above considerations are based on the simple elasticity theory assuming that E is constant and independent of the stress. This assumption is not valid for concrete, but it is on the safe side. This explains why actual lines have been deflected in excess of the safe angles predicted by above considerations without causing any damage to the joints.

The following examples illustrate the advantage of wide joints and thick packers on the permissible joint deflections.

Example 1. Packer (Joint) is full width of wall.

Outside diameter: 2220 mm

Inside diameter: 2000 mm

Wall and Joint Thickness: $t = t_j = 110$ mm

 $r_i / r = 0.90$

Jacking Force: 8750 kN

 $\max \sigma_j = 40$ MPa

 $E_c = 40\,000$ MPa

 $E_p = 150$ MPa

Pipe Length, $L = 3000$ mm

Compressed Packer Thickness, $a = 15$ mm

$$\text{Hence: } \sigma_j = \frac{8750 \times 10^3}{(2000 + 110)110 \times \pi} = 12.0 \text{ MPa}$$

$$\text{and: } \frac{\max \sigma_j}{\sigma_{jo}} = \frac{40.0}{12.0} = 3.33 \text{ and from Fig 5.1}$$

$$\frac{\max \sigma_j / \sigma_{jo}}{z / r} = 3.2$$

$$E_j = \frac{15 \times 110 \times 150 \times 40000}{15 \times 110 \times 40000 + 3000 \times 110 \times 150} = 85.7 \text{ MPa}$$

$$\phi = \frac{15 \times 12}{85.7 \times 1110} \times 3.2 = 0.00606 \text{ (Rad.)} = 0^\circ 20.8'$$

Example 2. Packer (Joint) is not full width of wall.

Outside diameter: 2220 mm

Inside diameter: 2000 mm

Wall, $t = 110$ mm

Joint, $t_j = 80$ mm

$$r_i / r = \frac{1000}{1080} = 0.93$$

Jacking Force: 8750 kN

 $\max \sigma_j = 40$ MPa

 $E_c = 40\,000$ MPa

 $E_p = 150$ MPa

Pipe Length, $L = 3000$ mm

Compressed Packer Thickness, $a = 15$ mm

$$\text{Hence: } \sigma_{jo} = \frac{8750 \times 10^3}{(2000 + 80)80 \times \pi} = 16.7 \text{ MPa}$$

$$\text{and: } \frac{\max \sigma_j}{\sigma_{jo}} = \frac{40.0}{16.7} = 2.40 \text{ and from Fig 5.1}$$

$$\frac{\max \sigma_j / \sigma_{jo}}{z / r} = 1.5$$

$$E_j = \frac{15 \times 110 \times 150 \times 40000}{15 \times 110 \times 40000 + 3000 \times 80 \times 150} = 97.1 \text{ MPa}$$

$$\phi = \frac{15 \times 16.7}{97.1 \times 1080} \times 1.5 = 0.00358 \text{ (Rad.)} = 0^\circ 12'$$

When comparing with Example 1 note the reduction in deflection angle caused by reduced joint width.

Example 3. This is identical to Example 2 with the exception that the pipe length is halved. It then follows:

$$E_j = \frac{15 \times 110 \times 150 \times 40000}{15 \times 110 \times 40000 + 1500 \times 80 \times 150} = 117.9 \text{ MPa}$$

$$\phi = \frac{5 \times 16.7}{117.9 \times 1080} \times 1.5 = 0.00295 \text{ (Rad.)} = 0^\circ 10.1'$$

For a 3000 mm length of pipeline with 2 joints the deflection would be $0^\circ 20.2'$ or 68% greater than for the line with 3000 mm long pipes.

Example 4. This is identical to Example 3 except that the packer thickness is doubled.

$$E_j = \frac{30 \times 110 \times 150 \times 40000}{30 \times 110 \times 40000 + 1500 \times 80 \times 150} = 132.0 \text{ MPa}$$

$$\phi = \frac{30 \times 16.7}{132.0 \times 1080} \times 1.5 = 0.0053 \text{ (Rad.)} = 0^\circ 18.1'$$

Note that a doubling of packer thickness has increased the deflection by 80%.

6. The Pipe Jacking Technique

6.1 Development

The mechanisation in the last couple of decades, and in later years the automation of pipe jacking has had the following aims:

- i) To reduce the labour content of the operation.
- ii) To increase the control over the operations.
- iii) To allow the jacking of pipes 800 mm and less in diameters.

Reports of operations carried out 40 or more years ago refer to advances per shift around 1.5 m. Today with a 3-4 man crew of experienced men 2.5-5 m/shift are achieved on average with peak performance of 10-15, and even higher outputs for the smaller diameters

Similarly laying tolerances have improved. Acceptable tolerance specifications range from ± 30 -100 mm in both vertical and horizontal directions, and tolerances actually achieved range from ± 10 -20 mm.

The fact that the majority of pipelines belong in the below 800 mm diameter range has been a strong incentive to develop suitable equipment for use in these diameters. Equipment including sophisticated cutting heads, spoil disposal conveyors and steering devices has resulted.



6.1 Development

The preparation of a pipe jacking operation commences with the excavation of the jacking pit -if such is required. The pit wall must be reinforced to withstand the maximum jacking force envisaged.

“While it is relatively easy to design bearing areas, grillages, piles, or ground anchors to resist the jacking loads, deflection can become a major problem. If insufficient rigidity is available, some of the jack effort and ram travel will be lost in overcoming elastic deformations. Deflections can cause eccentric loads to the jack base or ram head with subsequent seal failure, fracture of the jack body or bending of the ram.” (Ref 1).

Where the jacking operation is under an embankment a pit is not required and the reaction may be taken by anchors sunk into the ground or through rods anchored at the far side of the embankment. Launching pad or guide rails are constructed allowing pipes to be accurately aligned in direction and grade.

6.3 The Shield

In well planned and executed jacking operations the lead pipe is equipped with a sharp edged shield which serves the two-fold purpose of reducing the resistance to the pipe entering the soil and minimizing the quantity of soil spilling into the pipe. The latter can be further enhanced by providing one or more baffles in the top segment of the opening.

Depending on the type of soil and the presence of groundwater these precautions may be inadequate and chemical stabilization, freezing and compressed air at the face of the excavation have all been used to prevent unscheduled entry of soil into the work area.

The shield may also be equipped with individual jacks which allow it to be tilted and thereby making

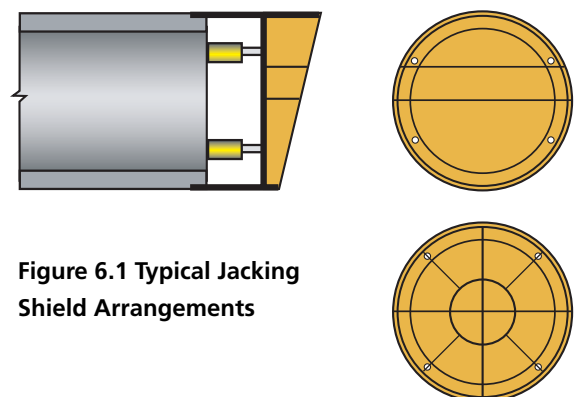


Figure 6.1 Typical Jacking Shield Arrangements

6.4 The Jacking Operation

When jacking short to medium lengths the jacking force is provided by jacks located at the pit and transferred to the pipe through a jacking head distributing the load evenly along its periphery.

“The jacks should all be of the one size and with a total capacity well above estimated jacking loads. While a stroke exceeding the pipe length will avoid the use of spacers it is usually uneconomical to purchase jacks with strokes of this order. Short stroke jacks although increasing the handling problems can reduce the size of the jacking pits. Jacks operate at a relatively high pressure – even the so-called low pressure jacks operate at 15 MPa. Jacking equipment should be clean and well maintained – particularly the hydraulic oil and filters. At least one spare jack should be kept on site. If one jack fails the remaining jacks may have sufficient capacity to push the pipe -however, in most jack configurations the removal of one jack will apply an eccentric load to the pipe.

Although jacking rates are relatively slow (e.g. 0.3 m/hr.) power operated jacks should be used to avoid the uneven jacking and extra labour associated with manual jacks”. (Ref 1).

When jacking from only one position the jacking force increases with the length of the section jacked. It is therefore usual when jacking long lines to introduce intermediate jacking stations where the force is introduced between the pipes thus reducing the maximum force required. In this case the rear pipe section acts as anchor for the reaction to the jacking force pressing the front section forward.

The pipe joints for such intermediate jacking stations will have to be specially designed as provision must be made for both a considerable joint gap to be developed without the joint coming out of alignment and for hydraulic jacks to be accommodated within the edges of the pipe wall.

In some instances this approach has been used to the extent that all jacking except of the last 2-3 pipes to have entered the line is done from intermediate stations. The extreme in this development is to carry out jacking at each joint and to limit the movement to one pipe at a time. In this instance the jacking is done by inflating rubber tubes placed in the joints and by successive inflation and deflation of the tubes a worm-like advance is achieved.

6.5 Excavation

“Excavation equipment is selected on the basis of job size, pipe size and type of ground. Normal method is to use short handled picks and shovels plus miscellaneous pneumatic equipment, e.g. clay spaders, jackpicks. In the very large jobs the expense of a ‘mole’ may be warranted. These generally have their own built in cutting and removal system.

Removal of spoil is usually with

- (1) a handcart
- (2) conveyor belt
- (3) small machines

Handcarts are commonly used in the smaller pipes. Providing the pipe slope is not severe and the pipe is kept reasonably clean quite heavy loads (1-2 tonnes) can be pushed. Small power winches assist in adverse circumstances.

Conveyor belts are an excellent means of transferring material. As the pipe-line is continually increasing the conveyors must have quick means of adjusting flight lengths.” (Ref 1).

Where groundwater is a serious problem compressed air has been used to counterbalance the water pressure either by creating a compression chamber immediately behind the cutting face or for smaller diameters by pressurizing the whole pipeline. Here also augers or rotating cutting heads are used. In the latter case the pressure on the cutting head may be applied by the grout pressure being maintained behind the head.



6.6 Control of Operation

Consistent control of direction and grade is essential, a task which in recent years has been vastly simplified by the use of laser beams. The level and direction of the progress of the pipeline should be plotted in order to allow early adjustments as instant correction to direction of jacking cannot be made.

Fig. 6.2 (a) shows correction to the direction of jacking having been delayed until the pipeline has intersected the projected course. The result is that pipeline overshoots in the opposite direction before the corrective measures take effect.

Fig. 6.2 (b) shows the correction having been implemented at an earlier stage resulting in a much more accurate operation than in Fig. 6.2 (a).

Corrections can be made in a variety of ways as, for instance:

- i) By vertical and horizontal adjustments of jacking force position.
- ii) By excavating ahead to correct line and grade (cohesive soils only).
- iii) By adjustments to the shield. (Fig. 6.1)

A variation to (ii) has also been used in case of larger pipelines. Here a pilot line was first constructed near the invert and an accurate concrete cradle cast for the larger pipeline to slide on. An expensive but effective way of ensuring close construction tolerances.

6.7 Safety

Pipe jacking projects like all operations below ground require careful attention to safety requirements. Poisonous gases whether generated by the equipment used or emanating from the soil excavated must be removed, and mechanical equipment must be well screened having regard to the cramped working conditions often existing on projects of this nature.

Power requirements are ideally supplied by electricity or compressed air as internal combustion engines will require added ventilation and are very noisy in such a confined space. High pressure hydraulic hoses and connections must be meticulously maintained and industrial safety regulations governing the use of laser must be observed. In general local mining regulations must be followed with regard to plant and installations, and electric lighting in most instances needs to be limited to 32 volt.

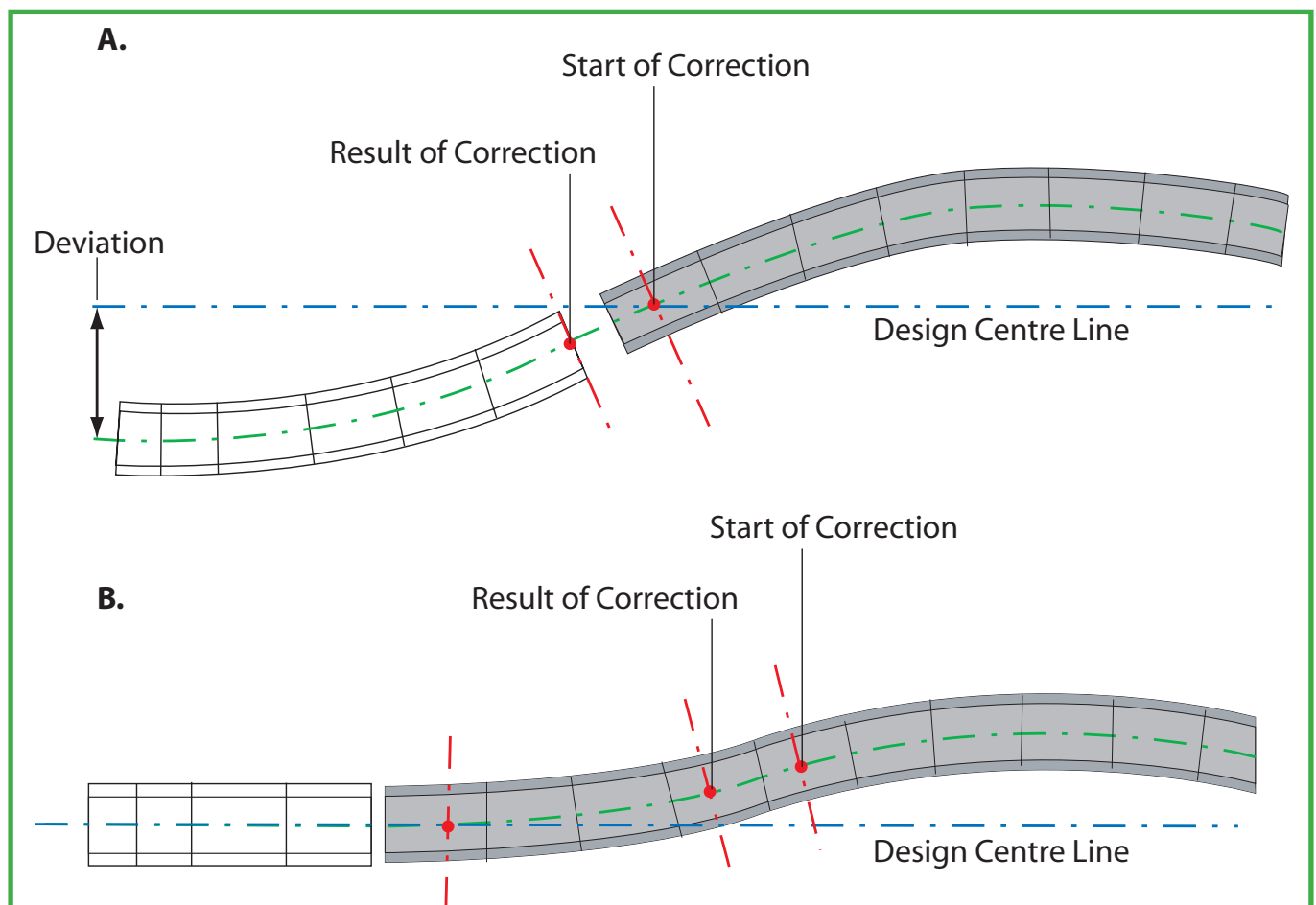


Figure 6.2 Steering of Pipeline

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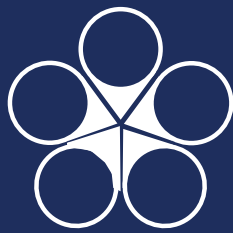
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