



Jetting-Assisted Sheet Pile driving

Jetting as an aid to sheet pile installation



Jetting: an aid to sheet pile installation

Although jetting-assisted sheet pile driving is a known technique, the results obtained with it are too often held confidential or lost in the unfathomed depths of archived projects. Because information is not generally made sufficiently public, the technique does not get the attention it deserves, and when it actually is used, the methods tend to be contractor-specific, not taking account of the results of broader research and experience by others.

This brochure is merely intended to make public the results of experiments instigated by ArcelorMittal in France, experiments which back up previous studies by geotechnical experts in Germany, to disperse any doubts project owners and designers might have about the technique, and to highlight some basic guidelines for contractors.

Questions people have about jetting assisted sheet pile driving are:

- what are the advantages of the technique?
- what kinds of soil are suitable for the technique?
- what are the principles for optimizing the jetting technique for different soil types?
- what happens to the surrounding ground?

The paper "Jetting-Assisted Sheet Pile Driving" reprinted below was presented at the 9th International Conference on Piling and Deep Foundations held in Nice in June 2002*.

It sums up the results of instrumented trials carried out between 1998 and 2001 on four sites under different geological conditions:

- clay at Mittersheim, in eastern France
- gravel at Strasbourg, near the Rhine
- sand and gravel at Lyon
- molasse at Toulouse.

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Jetting-Assisted Sheet Pile driving

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Since 1997, in partnership with the Laboratoire Central des Ponts et Chaussées in Strasbourg, ArcelorMittal has been carrying out a vast study to qualify the improvements jetting can make to vibratory driving of steel sheet piles, and to understand its effect on the surrounding ground and on the sheet piles themselves.

The process basically involves discharging a fluid (mostly water, sometimes in association with air) at controlled pressure and/or flow rate near the toe of the sheet pile being driven. The steel jetting pipes are attached to the sheet pile and are connected to the pumps by hoses. The jet of fluid loosens the soil, thus reducing the resistance at the toe of the sheet pile during driving. Depending on ground conditions, the fluid that flows along the pile can reduce skin friction.

Introduction

Since 1997, ArcelorMittal, in partnership with the Laboratoire Central des Ponts et Chaussées and the Laboratoire Régional des Ponts et Chaussées de Strasbourg, has been carrying out a vast study to qualify and quantify the improvement jetting can make to vibratory driving of sheet piles and understand its effect on the surrounding soil.

Jetting is combined with a sheet pile driving process, usually vibratory driving but sometimes jacking. The process basically involves discharging water under pressure near the toe of the sheet pile being driven.

The rigid steel jetting pipes are usually welded to the pile, with hoses connecting them to the jetting pumps. The water jet loosens the soil, reducing the resistance to penetration of the pile toe during driving.

Under some ground conditions, the water flowing along the pile acts as a lubricant and could reduce skin friction. Jetting enables sheet piles to be successfully driven into dense soils. It generally speeds up pile installation and reduces induced vibration, without damaging the piles.

Photo 1 shows the jets emerging from the pipes at the pile toe. It was taken during a test of jet operation, prior to driving.

Four sites with different geological characteristics were chosen:

- clay at Mittersheim, in eastern France
- gravel at Strasbourg, near the Rhine
- sand and gravel at Lyon
- molasse at Toulouse.

Each trial produced its batch of data and contradictions, contributing to overall thinking on the matter. The following article gives a brief review of the trials performed, results obtained, and analyses in progress.

It is important to remember that at this stage in the research, the conclusions are only valid for the geotechnical conditions at each site and cannot be extrapolated without specific testing.

However, the increasingly widespread use of this method in a number of countries, and on very large projects such as metros and railway lines, etc., has resulted in a significant increase in the amount of data and feedback on the technique.



Photo 1

Toe of U sheet pile with two jets in action.

Mittersheim

Site characteristics

The soil at Mittersheim was clay, slightly overconsolidated beyond a depth of 5 m, requiring the use of a heavy pile hammer beyond 6 m penetration depth.

Consistency of the soil was medium to good, with the following characteristics:

- $p_1^* = 0.6$ to 2.5 MPa
- $w_1 = 50\%$ to 60%, $I_p = 20$ to 35
- $\varphi = 25^\circ$ to 30° with $c' = 0$ to 20 kPa.

Configurations investigated

The following configurations were investigated:

- AZ 18 and L 3S sheet piles, length 9 m, driven as double piles
- 2, 4 or 5 jets per double pile
- open jet pipe end or directed jet.

Equipment used

The driving equipment was an ICE 416-L hydraulic vibrator and a Delmag D22 diesel hammer.

KSB rotary pumps with single speed and double discharge (for 2 and 4 jets) delivered jetting water. The fifth jet was provided with an extra piston pump.

Main results

Taking into account the head losses, jet pressure at the nozzle was in a range of 0.5 to 1.0 MPa. Flow rate was 250 l/min per jet.

Subsequent experience seems to show that a much lower flow rate would have been sufficient (compare with the Toulouse project, for instance).

Considering the soil limit pressures ($p_1 = 0.6$ to 0.8 MPa over the first six metres and 2.5 MPa beyond this depth), it is understandable that the “mechanical” action of jet pressure is more effective during the first few metres.

Jet number and pipe end shape were not found to be determining factors in this case. The time saving with 2 and 5 jet set-ups with open pipe ends or directed jets is in fact relatively modest in comparison with the practical complications involved (multiple pumping lines, shaped jet nozzles, etc.).

Note: An odd number of jets is not recommended. The asymmetry caused the piles to tilt during driving.

Jetting enabled the design depth of 8 m to be reached, whereas standard vibratory-driving alone met refusal at approximately 3.5 to 4 metres, and the diesel hammer had to be used to reach final depth.

Examination of penetration speeds reveals significant gains due to jetting: for both L 3S and AZ 18-piles installation time was reduced by a factor of 8 to 10.

Figure 1 compares driving times for an L 3S double pile simply vibrated to refusal, then impact driven (L 3Sv) to design depth, and a jetted/vibrated double pile fitted with four jets (L 3Svl).

Taking a look at the pore pressures, it was observed that they dissipated in 2 to 10 minutes.

Excavation revealed severe soil disturbance at a distance of 1–2 cm from the vibrated/jetted pile, which was less marked or almost untraceable beyond a distance of 10–20 cm from the pile.

Extraction tests (in 20 cm stages) revealed a 10–40% reduction in effective friction.

Extracted piles were impact-driven again to their original depth and further overdriven by 50 cm. These tests revealed a loss of toe resistance and skin friction of the same order of magnitude (as shown on figure 2 for L 3S sheet piles).

Conclusion for Mittersheim site (clay)

Jetting in clay proved to be a highly effective aid to pile installation, considerably shortening installation time with a limited risk of refusal, but caused significant disturbance to the soil immediately adjacent to the pile, leading to a loss of friction of the order of 10% to 40%.

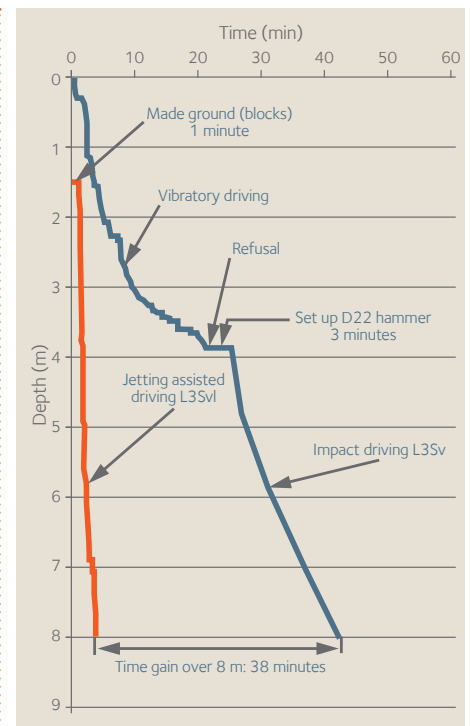


Figure 1
Comparative driving times.

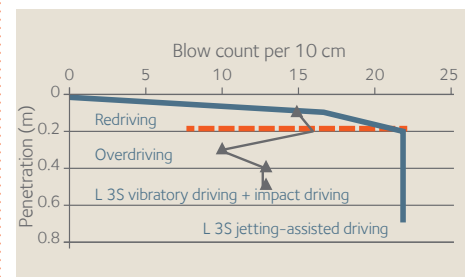


Figure 2
Redriving and overdriving-comparison between L 3S vibrated/impact driven piles and L 3S vibrated/jetted piles.

Strasbourg

Site characteristics

The second trial concerned highly pervious Rhine materials (0–60 mm gravel with a few >100 mm cobbles, poorly graded with no fine sand, overlain by local silt which was stripped from the trial site).

Mechanical properties were poor ($2.0 \text{ MPa} < p_i^* < 4.7 \text{ MPa}$).

The water table was found 1.30 m below ground level.

Under these conditions, the trial was intended to see if installation time and vibration would be reduced.

A preliminary test had shown that standard vibratory driving alone was possible.

Configurations investigated

The following configurations were investigated:

- L 4S and AZ 26 piles, length 14 m, driven as double piles
- 2 or 4 jets per double pile
- open pipe end or horizontally directed jet.

Equipment used

An ICE 416-L vibrator was used, with a KSB Multitec pump for the jetting.

Preliminary tests had shown there was little advantage in using for directed jets in this type of ground. A plain open pipe was therefore used for the remainder of the trial.

Main results

Jetting details remained substantially unchanged throughout the trial:

- flow rate 130 l/min
- net water pressure at nozzle 0.8 MPa.

A consequence of the high permeability of the soils was rapid dissipation of water pressure at a short distance from the nozzle end:

- pressure approximately 0.1 MPa near (10 cm from) the nozzle
- not measurable 50 cm from the nozzle.

The 10–30% gain in installation time was less than in the clay trial.

Two jets were less effective than 4, which may be explained by:

- the lower aggregate flow
- a less uniformly distributed pattern of jets.

Reducing nozzle size to increase jet pressure did not speed up the work.

In this highly pervious gravel therefore, the benefit of jetting does not come directly from jet pressure, but rather from the flow rate.

Jetting appears less attractive in gravel than in clay.

Induced vibration

Jetting distinctly reduced vibration measured at distances between 3 m and 20 m from the vibrator. The reduction in vibration was of the order of 20–30% below that measured when piles were simply vibrated into the ground.

Figure 3 shows induced vibration when vibrating an AZ 26 pile (blue plot) and when combining vibratory-driving and jetting (red plot), measured at ground level 11 m from the pile.

In both cases, measured vibrations did not reach what are normally considered critical levels (e.g. $v = 15 \text{ mm/s}$ at a distance of 10 m for embankments).

Influence on surrounding soils

Some slight soil consolidation was observed at the surface in all cases (in the layer of poorly compacted ground). Below this, the gravel does not appear to have been disturbed by the vibratory driving any more than by the jetting. It retained its original mechanical properties.

Soil/pile skin friction is also comparable with the two processes and complies with known values for these materials. Lastly, impact driving of extracted double piles revealed no changes in pile toe resistance after jetting.

Conclusions for Strasbourg site (gravel)

Jetting at the gravel site produced a slight improvement (10–30%) in terms of penetration rate, and reduced induced vibration by 20–30%.

This improvement did not cause any concomitant reduction in the mechanical properties (skin friction and toe resistance) of the surrounding soil.

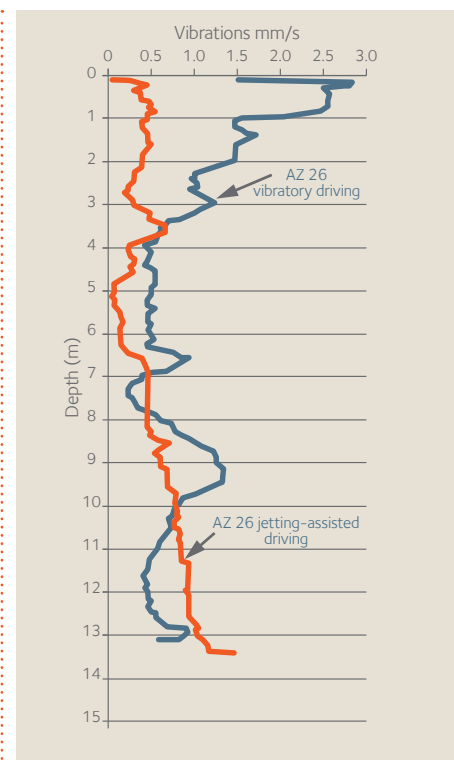


Figure 3 Induced vibration from vibratory pile driving (blue plot) and jetting-assisted driving (orange plot).

Lyon

The trial at Lyon was conducted at a jobsite experiencing difficulties. The trial was not so thorough as at the two sites previously described, and less instrumentation was used. The purpose was to assess the benefits and limitations of jetting in very compact sand and gravel alluvium of moderate permeability.

Equipment used

Single ArcelorMittal PU 20 sheet piles, 13 m long, were driven with a PTC 30 vibrator.

Standard vibratory driving soon reached refusal (3.0 m to 5.0 m below ground level).

Main results

Jetting made it possible to install the piles to depths of 8.0 m to 12.0 m in different areas. Despite this improvement, it was not possible to reach the required depth of 13.0 m. Refusal occurred in molasse formations, where the piles were unable to penetrate the dense layer by more than 1.0 - 1.5 m.

Effective jet pressures were low (0.3 MPa), well below the limit pressures of the in-situ soil ($p_i > 5$ MPa) (recorded average flow rate was 300 l/min).

The jetting on this site was not done under the best conditions. The excessively long (110 m) water hoses causing very high head losses and the large size (46 mm O.D. 35 mm I.D.) of the single jetting pipe on each sheet pile were unfavourable factors.

Better jetting conditions would probably have allowed the piling to penetrate deeper.

Toulouse

Site characteristics

The trial site was an opportunity to assess the efficiency of high pressure water jetting in helping penetration into the Toulouse molasse; a soil which has a reputation for being very difficult for driving steel sheet piles.

Jetting conditions were set on the basis of earlier lessons, especially those from the Mittersheim and Lyon site trials. Water pressure was increased for greater effect.

Equipment used

Characteristics were as follows:

- ArcelorMittal L 3S piles, length 10 m
- PTC 60HD vibrator
- GBE jetting pump (delivery rate 20 l/min, max pressure 16 MPa)
- two types of directed jet: conical nozzle and "organ pipe" nozzle.

Main results

The highly compact in situ molasse had pressuremeter moduli ranging from 35 to 82 MPa.

It was very difficult to install sheet piles by vibratory driving alone. Only the first one of the two reached design depth (10 m), the second one stopped at 7.10 m when the head failed. Driving had become difficult at a depth of 4.85 m. The required final depth of 10 m,

of which 6.50 m went through molasse, was achieved without difficulty by jetting.

Installation time between vibrated and jetted piles up to 2 times faster was recorded.

Combined with a powerful PTC 60HD vibrator, the following jetting conditions were found to be well suited to the conditions at the site:

- moderate flow rate of approximately 10 l/min per jet, with 2 jets per pile,
- water pressure in the molasse in excess of 4 MPa,
- directed jet nozzles.

They significantly reduced soil friction on the pile surface and provided a lubricating effect in the interlocks. As shown on photo 2, taken during the extraction of the piles, the jetted piles were pulled from the ground intact.

Induced vibration velocities were not significantly different between the two approaches: less than 4 mm/s at 10 m distance.

These vibrations can be considered moderate, in comparison with the limits usually set for the frequency ranges of the vibrator used (5-6 mm/s for sensitive buildings).

The molasses tested were not those displaying the highest mechanical resistance at the site (due to variations of facies and consistency). The very favourable results presented here can therefore not be extrapolated without precautions.

Conclusions for the Toulouse site (molasse)

Jetting with appropriate parameters, i.e. high water pressure (of the order of 4 MPa in molasse) and limited flow rate (10 l/min per jet), combined with a powerful vibrator made it possible to install sheet piles in this high consistency soil.



Photo 2
Extracting jetted U pile.

Conclusions

The trials described have demonstrated that the jetting process is particularly beneficial in "marginal" soils at the limit of what is feasible with standard vibratory driving: moderately consistent clays and molasse.

Unadapted parameters for jetting in the sand and gravel alluvium and molasse of Lyon highlighted the importance of correctly choosing the required jetting setup.

In all cases, jetting was associated with a reduction in induced vibration.

In several cases the jetting disturbed the surrounding soil adjacent to the sheet piles: there was a 10-40% reduction in skin friction in the clay but no significant effect was observed in the clean gravel.

The process can therefore be considered to aid vibratory pile driving in the case of soils with moderate or even quite high to high resistance.

There are also interesting prospects for injecting cement slurry at the pile toe (through the jetting pipes already in place) for the purpose of soil consolidation and/or watertightness.

The disadvantage of the possible disturbance to the surrounding soil would not only be cancelled out but the performance of the sheet pile wall would be considerably greater.

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Practical guide to jetting

The main parameters that will influence the choice of the several parameters of jetting assisted sheet pile driving are the geotechnical conditions.

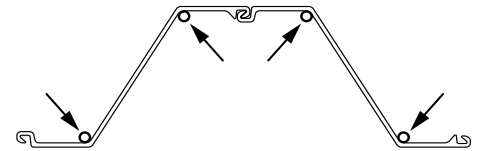
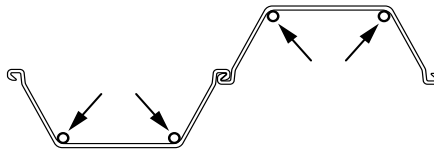
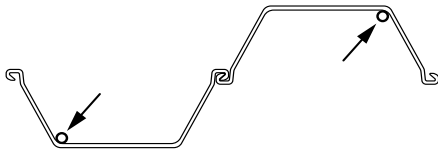
If the contractor does not have specific knowledge or experience relating to a particular site, preliminary trials should be carried out to

determine the appropriate jetting parameters and/or to optimize them.

In addition, logging of driving parameters (pump discharge pressure and flow rate, energy imparted, jetting pressure and flow rate, driving time, etc.) in accordance with the penetration depth, can be extremely useful. Nowadays quite

widespread, it is inexpensive and requires no special labour skills (there are many automated systems). The information obtained can be used to optimize the jetting parameters "as you go", to build up experience in the technique, and to establish a database which would be useful for other projects.

Low or medium pressure jetting (1.5 to 4 MPa)

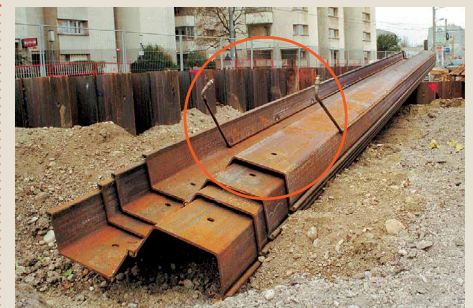


Low or medium pressure jetting is probably the best known version of the technique. It can be used to drive sheet piles in very dense soils.

Jetting pipes

Jetting pipes are 1/2" to 1" diameter steel pipes fixed into the angles of piles with a few tackwelds.

There are generally 2 or 4 jetting pipes per double pile. Experience has shown that an odd number or asymmetrical layout of jetting pipes causes the sheet pile to tilt during driving.



The jetting pipe ends flush with the toe of the sheet pile.

The top of the jetting pipe may be bent to facilitate connection of the supply hose.

Hoses

The rigid jetting pipes welded to the sheet piles are supplied by hoses connected to pumps.

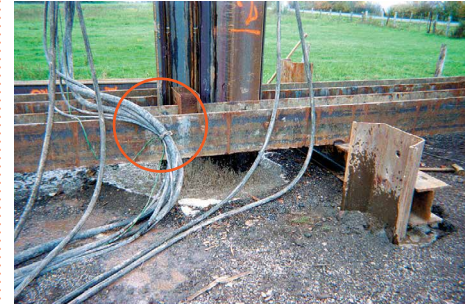
Hoses must be properly guided to prevent damage during sheet pile driving.



Hoses and jetting pipes being connected.



Hoses connected to jetting pipes (here at end of driving operation).



Water supply

Irrespective of the water supply system, a buffer tank must be provided to ensure that work can continue without interruption. The buffer tank should be reasonably close to the driving position in order to limit loss of water pressure in the hoses.



Installation with tank and pump for small project.



For long sheet pile structures, it may be very economical to use a truck-mounted container housing the pumps.

Pumps

Ideally there should be one rotary pump per jetting pipe.

The pump should be chosen in accordance with the required injection pressure (0.5 to 4 MPa; head loss must not be overlooked).

The water flow rate will depend on the type of soil: in permeable ground, a higher flow rate will be required (120 to 250 l/min per jet) but the

pressure will be lower (around 1 MPa); whereas in clayey or marly soil the much lower flow rate and a higher pressure (greater than the limit pressure of the soil) will increase the cutting of the ground by the water jet.

Water quality (clean or dirty water) will affect pump choice.

Inspection of jetting installation

Once the hoses have been connected to both the pump(s) and the jetting pipes, it should be checked that the system works correctly before starting driving.

However, care should be taken not to inject water at too high a pressure, because the sheet pile could be propelled upwards.



Sheet pile driving

To prevent clogging of the ends of the jetting pipes, it is recommended that jetting be in action right from the start of driving (care should be taken not to use too high a pressure before the sheet pile is securely in the ground).

Note: The disturbance to the surrounding soil as a result of jetting must be taken into consideration when calculating the bearing capacity of the jetted sheet pile (available skin friction reduced by 10 to 40% in clay).



When the driving rate reaches more than 1 m/min (German EAU recommendation), the injection pressure can be held stable until the required depth is reached.



Even after jetting, water may still pool around the sheet piles.

Very high pressure jetting (25 to 50 MPa)

Very high pressure jetting is being used increasingly in Germany and Scandinavia. It enables sheet piles to be driven both in silty and clayey soils and in extremely dense soils such as soft sandstone. It is also appreciated when there is a risk of settlement, for it requires a very low water flow rate.

With pump discharge pressure of 25 to 50 MPa, it is vital to use precision-engineered pipes for jetting (5 mm thick 30 mm dia. pipes, for

instance) and to have special nozzles screwed onto the end of the pipe ($\varnothing 1.5$ to 3 mm). Jetting pipes are attached at the top of the sheet pile and guided by welded ties along the pile. The bottom end of the nozzle should be located 5 to 10 mm above the toe of the pile. The German Committee for Waterfront Structures, Harbours and Waterways (EAU) recommends water consumption between 30 and 60 l/min/pipe, supplied by high-pressure

pumps (piston pumps for instance). Safety precautions taken during sheet pile driving must take account of risks associated with the very high pressure, and all operations must be carried out with care.

Trials in chalk, boulder clay, and stiff clay have not revealed any modification to the mechanical characteristics of the soil.

Conclusion

As these research and construction examples have shown, for a limited additional cost, jetting makes an improvement to the speed of sheet pile driving, something that everyone involved in engineering or construction projects will appreciate. In some cases, this improvement can be quite significant. In all cases, jetting-assisted sheet pile driving has proved to penetrate faster than traditional vibratory driving with predrilling, in soils where early refusal would be likely: this has been demonstrated in clays, in compact gravels, in marls, and in molasses. It also makes it possible to substantially reduce ground vibration velocities, a very important factor where the stability of nearby structures must not be compromised.

Jetting is growing in popularity in a number of countries with different geological conditions such as Switzerland, Germany, Scandinavian countries, and the Netherlands, and for some very long structures (often several kilometres, as for railway and metro lines), tens of thousands of tonnes of sheet piles have been driven with the assistance of jetting. Experience and data currently available for many types of soils, sheet piles, and driving plant have been considerably boosted.

Although every project must be studied in accordance with its own specific features, it can nevertheless be asserted that the success of the technique relies on use of symmetrically

arranged, small-diameter jetting pipes, and on limitation of head losses. The decisive parameter in gravelly soils will be the flow rate, and in cohesive soils it will be pressure. When all the parameters are correctly chosen, jetting is also a valuable and effective aid for driving sheet piles without disturbing the gravelly soils and which induces a slight to moderate reduction in skin friction in clayey soils. Moreover, the possibility of using jetting pipes to inject cement grout at the bottom of a sheet pile wall is an interesting prospect for improving toe strength and/or watertightness.

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