

# TECHNICAL NOTE 013

## Steel Sheet Piling - Drivability vs SPT-N Values; Vibrations & Noise Level



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### Keywords

SPT-N values, Drivability, SSP section modulus, installation method, vibrations, noise levels, vertical load carrying capacity

### Synopsis

Steel sheet pile (SSP) wall is a common wall type to facilitate deep excavations. The SSPs are required to be driven to a prescribed depth below the final excavation level to prevent (i) kick-out and (ii) hydraulic types of instability. In assessing the drivability of SSPs, it is necessary to review the sub-surface ground conditions and the driving methods. In some situations where hard-driving of SSP is anticipated, the section modulus of the SSP could be solely controlled by the drivability rather than the strength requirement as derived from the ELS design.

Guidance is given for determining the SSP section modulus with respect to SPT-N values of granular soils. Simple methods for calculating vibration level (in terms of peak particle velocity, mm/s) and noise level (in dB) during pile driving are provided as well as that for the vertical load carrying capacity of SSP.

### 1.0 Introduction

As documented in many technical literatures, SSPs could not normally be driven through soil stratum with SPT-N values greater than **50** easily. Hard-driving using strong SSP sections might then have to be employed. Otherwise, other installation methods such as those aided by pre-boring, water-jetting, etc might have to be considered, but these methods are not the topic of this technical note.

The density (or compactness) of non-cohesive soils can be correlated to the results of various field test methods as shown in the table below.

| SPT<br>(N Values) | CPT<br>(MN/m <sup>2</sup> ) | Pressuremeter Test<br>(MN/m <sup>2</sup> ) |                | Density    |
|-------------------|-----------------------------|--|----------------|------------|
|                   |                             | P <sub>L</sub>                             | E <sub>M</sub> |            |
| < 4               | 2.5                         | < 0.2                                      | 1.5            | Very loose |
| 4 – 10            | 2.5 – 7.5                   | 0.2 – 0.5                                  | 1.5 – 5.0      | Loose      |
| 10 – 30           | 7.5 – 15                    | 0.5 – 1.5                                  | 5.0 – 15       | Compact    |
| 30 – 50           | 15 – 25                     | 1.5 – 2.5                                  | 15 – 25        | Dense      |
| > 50              | > 25                        | > 2.5                                      | > 25           | Very Dense |

**NB** – P<sub>L</sub> is Limit Pressure; E<sub>M</sub> is Deformation (Ménard) Modulus

### 2.0 SPT-N Values Vs SSP Section Modulus

The SSP section selected must be capable of being driven through the various soil strata to the required penetration depth. The greater the surface area of the SSP profile, the greater the driving force required. It follows that there is a definite limit to drivability of a given SSP section and steel grade being used. The following table gives some guidance for selection of SSP section modulus, based on a simple relationship with SPT-N values for non-cohesive soils, and with using impact hammers.

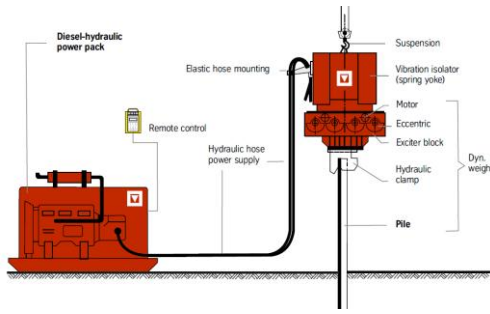
| SPT<br>(N Values) | SSP Wall Modulus (cm <sup>3</sup> /m) |                  |
|-------------------|---------------------------------------|------------------|
|                   | Low Yield Steel                       | High Yield Steel |
| 0 – 10            | 500                                   |                  |
| 11 – 20           |                                       | 500              |
| 21 – 25           | 1,000                                 |                  |
| 26 – 30           |                                       | 1,000            |
| 31 – 35           | 1,300                                 |                  |
| 36 – 40           |                                       | 1,300            |
| 41 – 45           | 2,300                                 |                  |
| 46 – 50           |                                       | 2,300            |
| 51 – 60           | 3,000                                 |                  |
| 61 – 70           |                                       | 3,000            |
| 71 – 80           | 4,000                                 |                  |
| 80 – 140          |                                       | 4,000            |

**NB** – Hard driving of SSP is anticipated in gray shaded area.

### 3.0 Installation Equipment for SSP

Installation equipment for driven SSP includes two broad families, ie Impact Drivers and Vibratory Drivers. Their suitability for use in different non-cohesive ground conditions, as represented by SPT-N values, is shown in the table below.

| Installation<br>Equipment      | SPT-N Values |         |         |      |
|--------------------------------|--------------|---------|---------|------|
|                                | 0 – 10       | 11 – 30 | 31 – 50 | > 50 |
| <b>Impact Drivers</b>          |              |         |         |      |
| Small Drop /<br>Hydraulic Drop | A            | A       | B       | C    |



Working principle of vibratory hammer



Vibratory hammer



Hydraulic drop hammer



Double-acting hydraulic hammer

|                             |   |   |   |   |
|-----------------------------|---|---|---|---|
| Large Drop / Hydraulic Drop | C | B | A | A |
| Air Hammers                 | A | A | C | D |
| Diesel Hammers              | C | B | A | A |
| <b>Vibratory Drivers</b>    |   |   |   |   |
| Small Vibro                 | A | B | B | D |
| Large Vibro                 | B | A | B | C |

**NB –**

**A:** Most suitable; **B:** Suitable; **C:** Not Ideal; **D:** Not suitable

#### 4.0 Vibrations & Noise Level

Some simple methods for determining approximate magnitudes of vibration and noise levels are given below.

##### 4.1 Vibrations

When an SSP is driven into ground, some of the driving energy is transmitted into the adjacent soils and can be experienced on the surface as vibrations, which could be gauged by measuring the induced **peak particle velocity (PPV)** in mm/s. An **empirical** equation can be used to estimate the PPV given the hammer energy per blow (or per cycle).

$$v = \frac{C\sqrt{W}}{r}$$

where

v is the estimated PPV (mm/s)

C is a parameter related to soil type and hammer (see table on the right for values of C)

W is the hammer energy per blow or cycle (Joule/blow or Joule/cycle)

r is the horizontal distance from the piling operation to the point of interest (m)

##### Worked Example

**A)** A vibratory hammer is used for driving SSPs in medium dense sands and gravels. The vibratory hammer has a power of 120kW and an operating frequency of 38 Hz. The PPV at distances of 2m and 10m can be calculated as follows.

Hammer energy for vibratory hammer:

$$W = 120,000 \text{ (Nm/s)} \div 38 \text{ (Hz, ie cycle/s)} \\ = 3,160 \text{ Joule/cycle}$$

Taking C = 0.7 (see table below) and for r = 2m,

$$v = \frac{0.7\sqrt{3,160}}{2} \\ = 20 \text{ mm/s} \\ = 4.0 \text{ mm/s at } r = 10\text{m}$$

**B)** A hydraulic hammer is used for driving SSPs in medium dense granular soils. The hammer weighs 3,000kg and is falling through a height of 0.85m. The PPV at distances of 5m and 20m can be calculated as follows.

Hammer energy for drop hammer:

$$W = m.g.h \\ = 3,000(\text{kg}) \times 9.81(\text{m/s}^2) \times 0.85(\text{m}) \\ = 20,516 \text{ Joules}$$

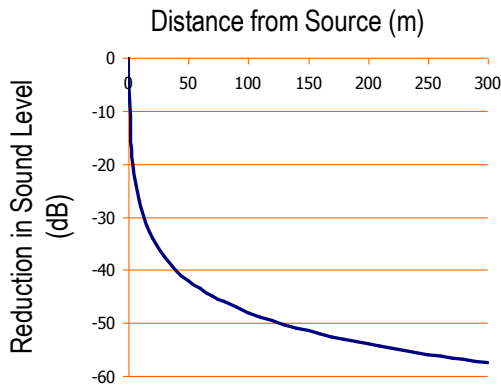
Taking C = 0.75 (see table below) and for r = 5m,

$$v = \frac{0.75\sqrt{20,516}}{5} \\ = 21.5 \text{ mm/s} \\ = 5.4 \text{ mm/s at } r = 20\text{m}$$

| Driving Method    | Ground Conditions   | C    |
|-------------------|---|------|
| Impact Drivers    | Very stiff cohesive soils, dense granular media, rock, fill with large solid obstructions | 1.0  |
|                   | Stiff cohesive soils, medium dense granular media, compact fill                           | 0.75 |
|                   | Soft cohesive soils, loose granular media, loose fill, organic soil                       | 0.5  |
| Vibratory Drivers | All soil conditions   | 0.7  |

##### 4.2 Noise Level

The type of noise associated with piling works depends on the method of installation. For example, pile driving using a drop hammer results in a well-defined impulsive type of noise. Diesel, hydraulic and air hammers also produce impulsive noise, although their striking rates can be much higher than drop hammers. With vibratory



**Reference:**

1. "Specifiers' Guide to Steel Piling" SCI Publication P308, The Steel Construction Institution;
2. "Installation of Steel Sheet Piles" Technical European Sheet Piling Association (TESPA);
3. "Piling Handbook" 8<sup>th</sup> edition, ArcelorMittal;
4. "Sheet Piling Handbook" 3<sup>rd</sup> edition, ThyssenKrupp

driving, the impulsive characteristic is virtually absent but an intermittent effect is still present.

Noise levels experienced in the vicinity of pile driving are a function of the noise power level,  $L_w$ , which is the air pressure fluctuation at the surface of the hammer (or the pile) expressed in dB, and the distance,  $r$ , from the source. An equivalent continuous A-weighted sound level, measured in **dB(A)**, over the working day,  $L_{aeq}$ , is given by the following equation:

$$L_{aeq} = L_w - 20 \cdot \log(r) - 8 \text{ dB(A)}$$

The noise power levels,  $L_w$ , for specific plant items can be obtained from suppliers.

The following are the characteristic noise levels for different pile drivers (measured at 7m from the machine):

|                    |   |                |
|--------------------|---|----------------|
| Impact Hammers     | : | 90 – 115 dB(A) |
| Rapid-Blow Hammers | : | 85 – 110 dB(A) |
| Vibratory Hammers  | : | 70 – 90 dB(A)  |

Typical noise levels of civil engineering plants are shown below for reference (measured at 7m from the machine):

|                   |   |           |
|-------------------|---|-----------|
| Piling Hammer     | : | 110 dB(A) |
| Crawler Crane     | : | 100 dB(A) |
| Pneumatic Breaker | : | 90 dB(A)  |
| Compressor        | : | 85 dB(A)  |

Worked Example

**C)** An impact hammer ( $L_w = 135$  dB) is used for driving SSPs. The  $L_{aeq}$  values at 10m, 20m, 40m and 80m are thus:

$$\begin{aligned} L_{aeq} &= 135 - 20 \cdot \log(10) - 8 = 107 \text{ dB(A)} \\ &= 135 - 20 \cdot \log(20) - 8 = 101 \text{ dB(A)} \\ &= 135 - 20 \cdot \log(40) - 8 = 95 \text{ dB(A)} \\ &= 135 - 20 \cdot \log(80) - 8 = 89 \text{ dB(A)} \end{aligned}$$

It can be seen from the above that for doubled distance, a 6 dB reduction occurs. The reduction takes the form shown in the graph above.

There are other noise considerations such as the calculation of  $L_{aeq}$  if the piling works is restricted to 50% of the working day; the calculation of the cumulative  $L_{aeq}$  for three noisy operations occur for limited periods of the working day, etc.

**5.0 SSP Vertical Load Capacity**

In some situations, the SSP installed might be required to take some vertical loads. For SSP installed in granular soils, a method of analysis (based on SPT-N values) has been used for many years. The ultimate load carrying capacity,  $Q_{ult}$  (kN), of an SSP in granular soils can be determined using the following equations (not for design requiring BD's Approval):

$$\begin{aligned} Q_{ult} &= Q_s + Q_b \\ \text{and } Q_s &= 2 \cdot N_s \cdot A_s \text{ (shaft resistance)} \\ Q_b &= 400 \cdot N_b \cdot A_b \text{ (base resistance)} \end{aligned}$$

where

- $N_s$  is the average SPT-N values over the embedded length of the SSP
- $A_s$  is the embedded area of the shaft of the SSP in contact with soil ( $m^2$ )
- $N_b$  is the SPT-N value at the pile base calculated using the following equation:

$$N_b = 0.5(N_1 + N_2)$$

Where

- $N_1$  is the smallest SPT-N values over the two effective diameters below the toe level
- $N_2$  is the average SPT-N value over 10 effective diameters below the pile toe.

It should be noted that, for submerged sands, the SPT-N value needs to be reduced ( $N_{red}$ ) using the following relationship for SPT-N values exceeding 15.

$$N_{red} = 15 + 0.5(N - 15)$$

- End -

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Gary Chou  
KMS / AGM (Technical)  
Technical Department  
Chun Wo Construction & Engineering Co Ltd  
E gary.chou@chunwo.com  
T 3758 8379  
F 2744 6937