ROCSCIENCE

Settle3

Dynamic Compaction

Verification Manual

Table of Contents

1. Verification Example: Dynamic Compaction of a Landfill 3

1.1. Description 3

1.2. Depth of Improvement 3

1.3. Applied Energy 4

1.4. Comparison with Unit Applied Energy Guideline 5

1.5. Post-Improvement SPT and Elastic Modulus 5

1.6. Depth of Crater Estimated 6

1.7. Induced Settlement 7

1.8. Peak Particle Velocity 7

1.9. Conclusion 8

1.10. Reference 8

1. Verification Example: Dynamic Compaction of a Landfill

Settle3 Version 5.026

1.1. Description

This example is derived from Jie Han's (2014) design example of dynamic compaction.

A 50 m-wide, 5 m-high highway embankment will be built over a thin (1m) fine-grained cover atop an 8.2 m landfill composed of silts, clays, and construction debris. The embankment will be constructed in five stages and the ground improvement will occur prior to the construction of the embankment. Pre-improvement SPT N values for the site was 10. Dynamic compaction will be used to increase the SPT N to suitable ranges above 20.

An 18.2t, 1.5m diameter tamper will deliver:

- **High-energy pass:** 6 drops from 30.2m on a 3m x 3m rectangular grid
- **Ironing pass:** 3 drops from 7.2m on the same grid

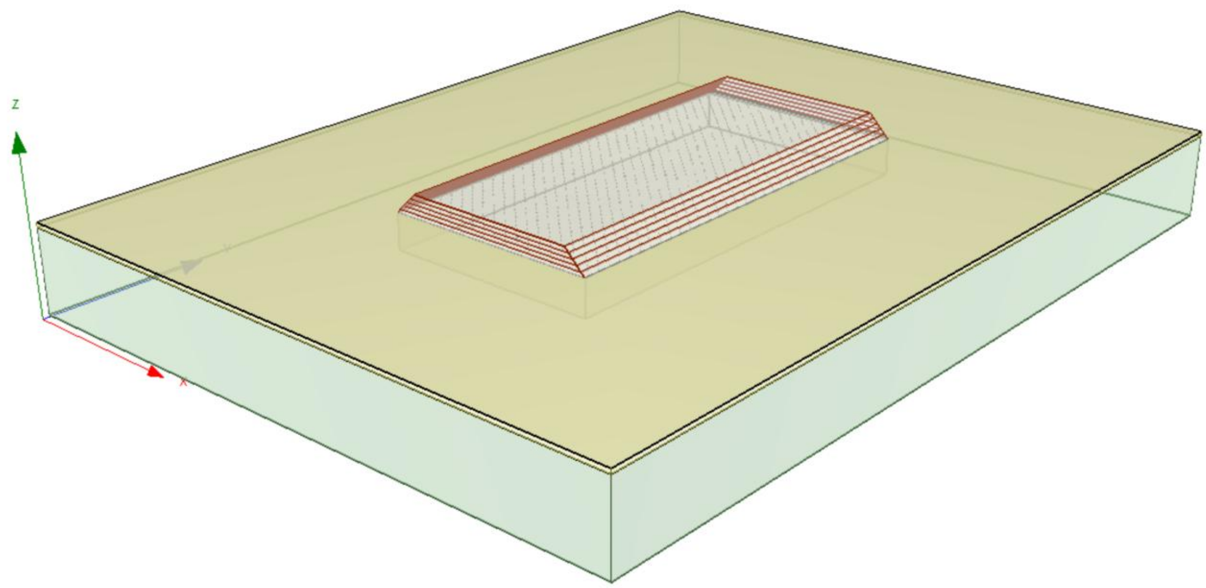

Figure 1: Verification Model in Settle3

1.2. Depth of Improvement

The depth of improvement can be calculated using the empirical formula shown in Equation 1:

$$\boldsymbol{D_i = n_c\sqrt{W_t H_d}} \qquad (1)$$

Where:

- n_c = empirical constant (dependent on soil type)
- W_t = tamper weight (ton)

- H_d = drop height (m)
- D_i = depth of improvement (m)

Where:

n_c: empirical constant

W_t: weight of tamper (tonnes)

H_D: drop height (m)

For a semipervious deposit, n_c can be taken as 0.35. Using the known values of the tamper weight and drop height, the depth of improvement is calculated as:

$$\boldsymbol{D_i = 0.35 * \sqrt{18.2t * 30.2m} = 8.2055m}$$

1.3. Applied Energy

The average applied energy per unit area of the high-energy pass is calculated using Equation 2:

$$\boldsymbol{AE = \frac{N_d W_t H_d}{A_e}} \qquad (2)$$

Where:

- N_d = number of drops
- W_t = tamper weight (ton)
- H_d = drop height (m)
- A_e = influence (equivalent) area of each impact point
    - s^2 for squares
    - $0.867 * s^2$ for equilateral triangular patterns
    - s = drop spacing

For a drop spacing of 3m, 6 drops per pass, a tamper of 18.2t, and a drop height of 30.2m, the applied energy from the high energy pass is calculated using Equation 2, substituting the values as follows:

$$\boldsymbol{AE_{HEP} = \frac{6drops * 18.2tonnes * \left(\frac{0.00981MN}{tonne}\right) * 30.2m}{(3m * 3m)} = 3.59\frac{MJ}{m^2}}$$

Similarly, the energy from the ironing pass can be calculated using the same equation:

$$\boldsymbol{AE_{IP} = \frac{3drops * 18.2tonnes * \left(\frac{0.00981MN}{tonne}\right) * 7.2m}{(3m * 3m)} = 0.428\frac{MJ}{m^2}}$$

The total applied energy is the sum of the applied energy from the high-energy and low-energy passes, shown in Equation 3:

$$AE_{total} = AE_{HEP} + AE_{IP} \quad (3)$$

This results in total energy of ~4.02MJ/m2 per pass.

1.4. Comparison with Unit Applied Energy Guideline

The total applied energy can also be obtained by the Unit Applied Energy for different soil types as shown in Table 3.10 of Jie Han (2014):

Table 3.10 Required Unit Applied Energy[a]

Soil Type	Unit Applied Energy (kJ/m^3)	% Standard Proctor Energy
Pervious coarse-grained soil	200–250	33–41
Semi-impervious fine-grained soil	250–350	41–60
Landfill	600–1100	100–180

Figure 2: Required Unit Applied Energy for Various Soil Types

For landfills, consider an average unit applied energy of 850kJ/m3. The total applied energy is calculated by multiplying the depth of improvement by the unit applied energy. For a depth of improvement of 8.2m, the required total applied energy would be 6.97MJ/m2. Dividing by two passes yields 3.485MJ/m2 per pass.

The differences between using the suggested values in the table and manual calculations can be explained by the fact that the 850 kJ/m^3 is an averaged guideline versus the precise theoretical energy computed from $W_t H_d$ per drop.

1.5. Post-Improvement SPT and Elastic Modulus

The improved SPT-N can now be estimated by the relationship between average SPT-N and Applied Energy chart in Figure 3:

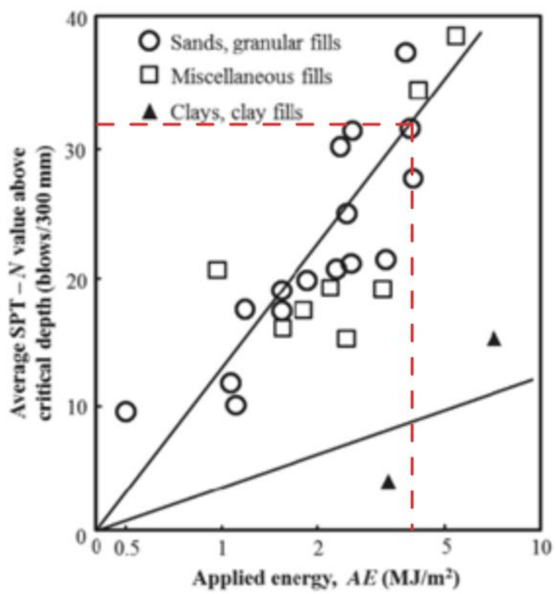

Figure 3.22 Average SPT *N* value after improvement (after Lukas, 1995).

Figure 3: Average SPT N after dynamic compaction

The improved SPT-N value is visually approximated to be between 32-33 blows/300mm. The improved elastic modulus is the product of the E/N ratio. Using the default value of 2, the improved elastic modulus is calculated as shown in Equation 4:

$$E_{improved} = \frac{E}{N} * 32.56 = 65.12\ MPa * \frac{101.97\ \frac{tonnes}{m^2}}{MPa} \approx 6640\ \frac{tonnes}{m^2} \quad (4)$$

1.6. Depth of Crater Estimated

Settle3 calculates the estimated depth of the impact crater using Equation (5):

$$log(d_{cd}) = -1.42 + 0.553 * log(N_d) + 0.213 * log(H_d) + 0.873 * log(W_t) - 0.435 * log\left(\frac{s_d}{d_t}\right) - 0.118 * log(p) \quad (5)$$

Where:

- N_d = number of drops
- W_t = tamper weight (ton)
- H_d = drop height (m)
- d_t = tamper width or diameter (m)
- p = contact pressure (t/m2)
- s_d = drop spacing (m)

For the given properties of the dynamic compaction, the depth of the crater is calculated as

$$d_{cd} = 10^{-1.42+0.553*log(6\ drops)+0.213*log(30.2m)+0.873*log(18.2t)-0.435*log\left(\frac{3m}{1.5m}\right)-0.118*log\left(\frac{18.2t}{\pi*\left(\frac{1.5m}{2}\right)^2}\right)} \approx 1.5m$$

1.7. Induced Settlement

The induced settlement is calculated using the formulation provided in Equation 6.

$$S = N_p * a_r * d_{cd} \tag{6}$$

Where:

- N_p= number of passes
- a_r = area ratio of improvement

$$a_r = \frac{A_c}{A_e}$$

Where:

- A_c= area of crater
- A_e= influence area of tamping point

- d_{cd} = depth of the crater
- S = estimated induced settlement

The area crater diameter can be assumed to be the same as the tamper diameter, resulting in a crater area of 1.767m^2:

$$A_c = \pi * \left(\frac{1.5m}{2}\right)^2 = 1.767m^2$$

The influence area was previously calculated as 9m^2, therefore the area ratio of improvement is approximately 0.20:

$$a_r = \frac{1.767m^2}{9m^2} = 0.196$$

The induced settlement can now be approximated by inserting the figures to Equation 6:

$$S = N_p * a_r * d_{cd} = 2 * 0.196 * 1.5 = 0.58776m$$

1.8. Peak Particle Velocity

Suppose there is a structure 20m away from the dynamic compaction site. The peak particle velocity can be estimated using Equation 7:

$$PPV = 70\left(\frac{\sqrt{W_t H_d}}{x_{dp}}\right)^{1.4} \tag{7}$$

Where:

- PPV = Peak Particle Velocity (mm/s)
- W_t = tamper weight (ton)
- H_d = drop height (m)
- x_{dp} = distance to drop point (m)

$$PPV = 70\left(\frac{\sqrt{18.2t * 30.2m}}{20m}\right)^{1.4} = 87.44\frac{mm}{s}$$

1.9. Conclusion

The results calculated in this verification manual are displayed next to the dynamic compaction region in the plan view of Settle3. The list of output results includes:

- Depth of Improvement
- Applied Energy from Ironing Pass
- Applied Energy from High Energy Pass
- Total Applied Energy
- CPT qc or SPT N post improvement
- Elastic Modulus After Improvement
- Depth of Crater
- Estimated Induced Settlement
- Peak Particle Velocity

Empirical Results
Depth of Improvement: 8.21 m
AE from Ironing Pass: 0.42835 MJ/m2
AE from High Energy Pass: 3.59 MJ/m2
Total Applied Energy: 4.02 MJ/m2
SPT N After Improvement: 32.56 blows/300mm
E After Improvement: 6640.68 t/m2
Depth of Crater: 1.5 m
Estimated Induced Settlement: 0.59 m
Peak Particle Velocity: 87.44 mm/s

1.10. Reference

Han, J. (2014). *Principles and Practice of Ground Improvement,* John Wiley & Sons