Finite element analysis of dynamic compaction in soft foundation

Wan-Li a*, Qiangkang- Gu a, Lihai- Su a, Binghui- Yang b, a*

a School of Engineering, Air Force Engineering University, Shaanxi, Xi’an 710038, China
b Lanzhou Air Force Logistics, LanZhou 730000, China

Abstract

Three-dimensional finite element analysis model was built by the quasi-static force method based on reconnaissance data of dynamic compaction in soft foundation. The ground was consolidated by dynamic compaction method, the variety rules between the number of tamping passes and the crater settlement were confirmed by analysis of ground deformation and pore pressure. The numerical simulation results of dynamic compaction show that the simulation results are in accord with the field test results on the whole, the numerical simulation can explain all kinds of phenomenon and can serve for construction design of dynamic compaction.

Main research methods of engineering science include theoretical study, model test and numerical analysis. We can not obtain analytical solution when referring with calculation of complex terrain boundary condition, anisotropy materials and nonlinearity of stress-strain. With continuous development of electron computing technology, simulation analysis on large project by numerical analysis[1-4] has been important method of modern theoretical research and engineering technical analysis. In the paper, three-dimensional finite element model was built and dynamic consolidation test area, B1-1 area, was comprehensively analyzed based on foundation treatment of a container terminal.
1. Pseudo-static method

Basic thoughts of pseudo-static method\[5\] as fellows: stress of contact surface between rammer and soil is deemed as static, the static from rammer make foundation deform, rammer undergo reaction force from foundation and move downward with foundation, the work of rammer by contact pressure eliminate power of rammer during the course, expression of the force can be deducted using function principle. Based on the substance of dynamic consolidation which make soil form non-recoverable plastic deformation. On the basis of the essence of dynamic compaction which produce soil form unrecoverable plastic deformation, Chenghua-Wang\[6\] summarize reinforcement mechanism into changing from gravity potential energy form rammer to plastic deformation energy of soil, and contact surface equivalent quasi-static force \( p_e \) can be obtained as follows:

\[
p_e = \sqrt{\eta k E_p W / \left[ C \left( 1 - \nu^2 \right) \right. \left. D^3 \right]}
\]

\( E_p \) - correspondent deformation modulus of \( p_e \); \( \nu \) - diameter or side length of rammer;
\( H \) - distance of fall of rammer; \( W \) - weigh of rammer; \( \eta \) - energy-efficient coefficient, its value is 0.67 by Cheng-hua Wang; \( C \) - shape of rammer, round set-hammer is 0.62, plane set-hammer is 0.89.

2. Constitutive selection

Ideal elastoplasticity model of Drucker-Prager was adopted in the paper. The Option of DP material uses Drucker-Prager yield criterion, known as the general Mises role. When internal friction angle is zero, it degenerate into Von Mises role. It adopt D-P yield criterion and Mohr-Coulomb role approximation in order to revise Von Mises role. Its flow rule can either use the associated guidelines and can use independent current guidelines, its plastic behavior is assumed to be ideal elastoplasticity.

Ideal elastoplasticity model of Drucker-Prager can be expressed as follows:

\[
F = \alpha I_1 + \sqrt{J_2} - k = 0
\]

\[
I_1 = \sigma_1 + \sigma_2 + \sigma_3;
\]

\[
J_2 = \frac{1}{2} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]
\]

\( I_1, J_2 \) respectively is first-invariant of stress tensor and secondary invariant of Partial stress tensor;
\( \theta_\alpha \) - load angle, \(-\pi/6 \leq \theta_\alpha \leq \pi/6\); \( \alpha \), \( k \) - constant related with internal friction angle \( \phi \) and cohesion \( c \), \( K = E_d / \left( E_0 - E_d \right) \), \( E_d \) - elastic modulus of foundation soil.

3. Model parameters

In order to comparison with site dynamic consolidation test and results of test numerical simulation, the same tamping energy and rammer parameters were adopted like spot, rammer weigh is 17.68t, rammer radius is 1.05m, tamping energy is 3000kj, tamping bits is 10. Calculation
width, length and depth of 20m form 25478 nodes and 136228 cells adopting 3-D four nodes cells (Fig.1).

It is a important problem to obtain calculation parameters coincidence with practical situation, its value directly effect calculating result. This numerical simulation parameters were obtained from post treatment soil parameter by wick drain preloading from B1-1 area.

4. Loading solution process

Contact stress of Rammer bottom is equi-distribution in finite element calculation of dynamic consolidation and simplest triangle-wave change law is adopted in time domain(Fig.2), its maximum stress is as follows:

\[ \sigma_{\text{max}} = v_0 \sqrt{MS / \pi \gamma^2} = \sqrt{2gh} \sqrt{MS / \pi \gamma^2} \]  \hspace{1cm} (3)

\( S \) - elastic constants, \( S = 2 \gamma E / (1 - \mu^2) \); \( v_0 \) - hammer velocity; \( \gamma \) - radius of rammer; \( M \) - quality of rammer; \( h \) - distance of fall of rammer; \( g \) - acceleration of gravity.

Loading time and unloading time as follows:

\[ t_{30} = t_{30} = 0.5 \pi \sqrt{M / S} \]  \hspace{1cm} (4)

5. Calculating result

5.1. Settlement

Comparison between numerical simulation of settlement and spot measured result was showed in Fig. 3 that they uniform on the whole and there is better simulation result.

5.2. Displacement

1) Surface displacement

Rammer impose strong impact force on surface and form large vertical displacement(Fig.3). With tamping times increased, every displacement increased and formed deeper rammer pit.

2) Vertical displacement under surface

Maximum area of vertical displacement take on a ellipsoid of 3-4 m radius and 7-8 m depth. With depth increasing, vertical displacement gradually decrease and became 0.01cm in 7-10m depth. It is showed that soil layer had tiny amount of compression under 8m. It is inferred that effective reinforcement depth is 8m based on vertical displacement. Periphery vertical displacement of rammer is less than the centre in the shallow and it show uneven compression. Almost vertical displacement between certain distance from the rammer center (more than the radius of
hammer) and rammer center show that settlement was even in depth, did not centralize the range of rammer radium, proved tamping energy smaller with more depth and take on even dispersion, that is to say there is geometry damping during energy transfer in foundation. Accordingly to concentration region of vertical displacement, Ram spacing of 3m in test area can make shallow compression even. To eliminate surface uplift and shallow small amount heterogeneity around pit, it can obtain best treatment effect filled with small energy level full rammer.

3) Lateral displacement under surface

Power of dynamic compaction is axi-symmetric, it is zero in the center of rammer, Area of large lateral displacement is around ellipsoid of radius of 5m and depth in 6m. It increase gradually from center line of rammer to outside, increment become maximum in the edge(about 1.25m) and decrease gradually far from rammer. Lateral displacement decrease gradually from shallow to depth. Because of different poisson ratio in of soil in different depth and hardness-softness between adjacent layer, the max displacement of testing point is irregular. It is showed by cloud chart of lateral displacement that there were vertical compression and lateral extrusion with dynamic compaction. Reinforce range by them are more than radius of rammer and accordance with simulated result.

5. 3. Pore water pressure

Pore water pressure increase mainly in the ellipsoid range under rammer. In the role of 3 000 kPa tamping energy, pore water pressure increase rapidly, pore water pressure in difference depth become maximum near 3m and its radius of influence is 3m. Increment of pore water pressure of coarse sand in shallow and fill stratum is large in the ellipsoid range and disappear quickly, So the coarse sand in shallow and fill stratum can be reinforced. Increment of pore water pressure in deep silt clays is small with every tamping, but excess pore water pressure disappear slowly and make press stack by more tamping, excess pore water pressure increased gradually make effective stress reduce in silt clays.

6. Conclusion

1) Dynamic compaction and spatial distribution of Pore water pressure concentrate in the area of ellipsoid around the center of rammer axis, they gradually decrease in horizontal direction off the rammer and in vertical orientation. So reinforcement effect of dynamic compaction pit is best and reinforcement range extend with tamping times increased. On the basis of special distribution of above parameters, 3 m rammer interval identified is reasonable in test area and uniformity tamping effect can be obtain in shallow and depth while uplift of surface need small energy level full rammer.

2) It is showed by numerical simulation that simulation mostly accord with measured result, measured result can explain every kind of phenomenon during construction and serve for construction design.

References:

[1] Xiao-nan Gong. Geotechnical computer analysis[M].Beijing: China Building Industry Press,2000
[2] Bai-li Zhu, Zhu-jiang Shen. Calculation soil mechanics[M]. Shanghai:Shanghai Science and Technology Press
[3] Jun liu,Zhong-kui Li. Current situation and development of dda method[J ].Chinese Journal of Rock Mechanics and Engineering, 2004 ,23 (5) :8392845
[4] Shen-qun Liu, Xiao Zhen. Finite element analysis of the settlement of soft clay soil roadbeds under traffic load[J ].Shanxi Architecture[J], 2008 ,34 (5) :122
[5] Si-hai Luo. Dynamic compaction and reinforcement effect calculation of dynamic replacement in soft foundation [D].
Hangzhou: Doctoral dissertation, Zhejiang university, 1999

[6] Cheng-hua Wang. Equivalent Pseudo-static method of dynamic reinforcement depth [A]. Sixth National Soil Mechanics and Foundation Engineering Conference Proceedings [C]. Shanghai: Tongji University Press, 1991: 617-620