The Effectiveness of Vibration Reduction Trenches in a Dynamic Replacement Project

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ABSTRACT

Umm Al Quwain Marina Phase I Project is located in northern United Arab Emirates. The site is located in an area where the ground consists of 6 to 7 m of very loose heterogeneous saturated silt and silty sand. More than 86,000 m^2 of the site has been treated using dynamic replacement. Due to the presence of existing structures in the vicinity of the ground improvement works vibration monitoring and control was implemented. In this paper, initially previous studies on dynamic compaction vibration will be reviewed, then the two cases of vibration monitoring programme for UAQ Marina will be described. First, particle velocities and their associated frequencies were measured at different distances from the pounder's impact point when no specific measures were implemented. Next, a vibration reduction trench was excavated and the vibration parameters recorded again. The interpretation of the results indicates that the vibration reduction trench has been able to efficiently reduce peak particle velocities to about one half the values when the trench was not installed. This study demonstrates that simple methods such as constructing vibration reduction trenches can be an effective way for controlling vibration damage when existing structures are nearby.

Keywords: dynamic replacement, ground improvement, vibration

1 INTRODUCTION

Dynamic compaction is a ground improvement technique in which the mechanical properties of the soil is improved by dropping a heavy weight (pounder) from a significant height a number of times onto a point and in a predetermined grid (Hamidi et al., 2009). Similarly, in dynamic replacement granular material is driven in the soft soil to form a large column and compacted using a pounder that is dropped onto a number of times onto the column location. The impacts create body and surface waves that propagate in the soil medium.

1.1 Waves

The body waves, i.e. the compression and shear waves, propagate radially outwards from the pounder impact point along a hemispherical wave front as shown by the heavy black lines of Figure 1 (Woods, 1968). Likewise, the Rayleigh or R-waves propagate radially outwards along a cylindrical wave front.

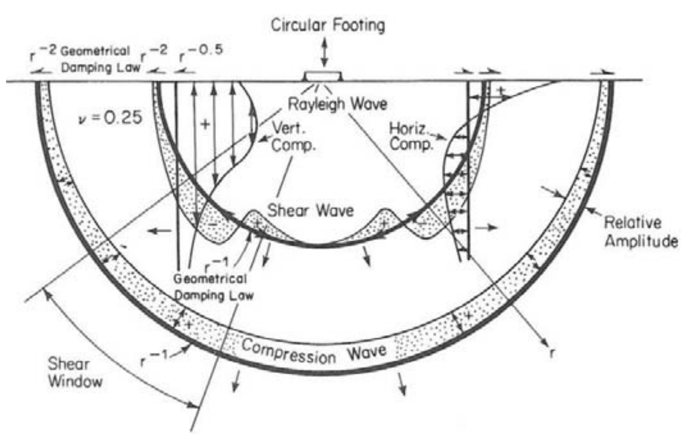


Figure 1. Distribution of displacement waves from a circular footing on a homogeneous, isotropic, elastic half space (Woods, 1968)

The volume of material that is encompassed by each of the waves increases as the waves travel away from the source. Hence, the energy density, i.e. the energy per unit volume, in each wave front decreases with distance from the source. This decrease in energy density and consequently the decrease in displacement amplitude is called geometrical damping.

Material damping is the result of energy loss due to hysteresis damping and internal sliding of soil particles (Thevanayagam et al., 2006), and is the decrease in vibration amplitude with distance from a source due to energy losses in the soil (attenuation). Attenuation should be distinguished from geometrical damping which occurs in elastic systems because of the spreading out of the wave energy from a source.

the amplitude of the R-wave decreases proportionally with the inverse of the distance from the vibration source (Ewing et al, 1957); however in soil the wave amplitude decreases faster as soil is not an ideal elastic medium and because there is an internal or material damping. As expressed in Equation 1, both geometrical damping and material damping can be taken into account for R-wave attenuation (Bornitz, 1931):

$$w = w_1\sqrt{\frac{r_1}{r}}e^{-\alpha(r-r_1)} \tag{1}$$

where r_1= distance from source to point of known amplitude; r= distance from source to point in question w= amplitude of the vertical component of the R-wave at distance r from source; and w_1= amplitude of the vertical component of the R-wave at distance r_1.

1.2 Peak particle velocity

Statistical research (Duvall and Fogelson, 1962) has shown that major damage correlates with particle velocity while minor damage correlates with acceleration. Hence, it is common practice to use particle velocity in lieu of particle acceleration for prediction of damage potential.

Peak particle velocity (PPV) generated by dynamic compaction or dynamic replacement can be estimated using empirical formulas. Hamidi et al. (2011a) have proposed the application of Equation 2 when the pounder impact energy (product of pounder weight and drop height) is in the range of 300 tm

$$PPV = 560d^{-1.1} \tag{2}$$

where d= distance from the pounder's impact point. This equation was later (Hamidi et al, 2011b) developed into the more general form of Equation 3.

$$PPV \ \leq 25\left(\frac{\sqrt{WH}}{d}\right)^{1.1} \tag{3}$$

W= pounder weight (tons) and H= pounder drop height (m)

PPV estimation may indicate that particle velocity will possibly exceed limits set by codes and standards and that implementation of specific measures could be required to reduce the damaging effects of the waves. These measures may include reducing impact energy or installing vibration isolators.

1.3 Isolation barriers

the concept of isolation by wave barriers is based on reflection, scattering and diffraction of wave energy. Wave barriers may be of solid, fluid or void zones in the ground. At a solid to solid interface both P and S-waves are transmitted, at a solid to fluid boundary only P-waves are transmitted and finally at a solid to void interface no waves are transmitted.

An active barrier is a barrier that reduces vibrations at the source. On the other hand, in passive barriers vibrations are screened at a distance. Woods and Richart and Woods (1968) have carried out broad investigations to develop guidelines for the design of active and passive barriers.

In Dynamic Compaction and Dynamic Replacement the impact location is constantly changing and it is not practical to construct an active barrier at the vicinity of moving points; however construction of active barriers at ground improvement boundaries and passive vibration reduction isolators in the form of excavated trenches are applicable. Based on the study of Thau and Pao (1966) it has been found that an increase in trench width does not cause a significant change in either the magnitude of reduction or the shape of the screened zone. Using boundary element method, Tsai and Chang (2009) have found that changes in either Poisson's ratio or trench width had insignificant influence on vibration amplitude changes. Poisson' ratio does not have a significant effect because the vibration isolation by a trench is primarily achieved by the screening of R-waves.

2 APPLICATION OF VIBRATIO REDUCTION TRENCHES IN UMM AL QUWAIN MARINA

Umm Al Quwain (UAQ) Marina is a master-planned community in the northern emirate of Umm Al Quwain in the UAE. This project envisages 6,000 villas and 2,000 townhouses, some 1,200 resort and hotel rooms, super markets, shopping centres, schools and health clinics. UAQ Marina Phase 1 consists of 277 two floor (ground and first floor) villas in Community 16 of which 127 villas are within the area (86,000 m^2) of discussion of this paper.

2.1 Ground conditions based on initial geotechnical investigations

Groundwater was recorded to be from 1 to 3 m below ground level. The preliminary geotechnical investigations that were based on SPT boreholes suggested that the site was composed of 2 m of very loose to medium dense silty sand with SPT blow counts ranging from 2 to 28 and with fines content less than 10%. This layer was followed by a 4.5 m thick layer of very loose to dense silty sand with blow counts of 0 to 35 and fines content of less than 15%.The next 3.5 m of soil then became silty sand with SPT blow counts of 16 to more than 50 and with fines content less than 20%.

2.2 Ground improvement solution

Based on these reports the project engineers designed strip footings on improved ground. Maximum footing width was 1.5 m under a uniform load of 140 kPa. Footing depth was defined as 1 m below ground level. Consequently, a specialist ground improvement specialist contractor was awarded a design and construct ground improvement contract. The proposed soil improvement technique was dynamic compaction.

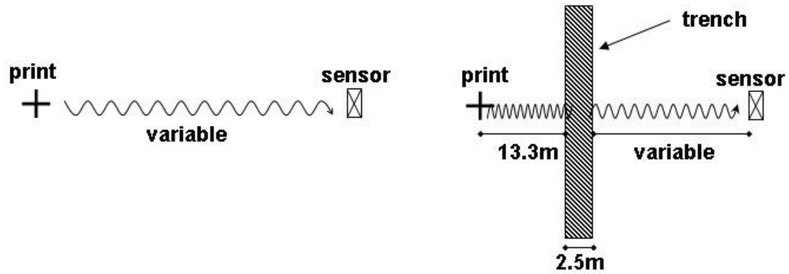
Once the contractor was on site, further geotechnical testing revealed a different soil profile and the presence of a 0.3 m thick previously unidentified very soft very silty sand to sandy silt (fines content in the range of 40 to 60%) layer at an upper depth of approximately 1.7 m to 2.1. Menard Pressuremter (PMT) limit pressure in this layer was 200 kPa.

Consequently, the ground improvement technique was modified to pre-excavated dynamic replacement by excavating the saturated soft material from below groundwater level, backfilling the excavation points with sand under groundwater level and placing mixed soil above ground water level.

2.3 Vibration monitoring

As dynamic replacement works were to be carried out as close as 20 m from existing and under construction structures concerns were raised that vibrations generated by the ground improvement works could damage the buildings. Hence, a vibration monitoring programme was developed to study the vibration parameters with and without the installation of vibration isolators.

In this programme initially a 14.5 ton pounder was dropped from the height of 20 m and radial, transversal and vertical particle velocities and associated vibration frequencies were measured at distances of 10 to 40 m, see Figure 2(a).



(a) *(b)*

Figure 2. (a) Vibration monitoring without a trench, (b) vibration monitoring with a trench

Next, as shown in Figure 2(b), a trench that was 25 m long, 2.5 m wide and 2.5 deep (to groundwater level) was excavated 13.3 m away from the pounder's drop point and the same parameters were measured again. In this phase the pounder used was 13 tons and the pounder drop height varied from 5 m to 18 m.

2.3.1 Vibration monitoring without an isolation trench

The measured PPVs and their corresponding frequencies for the case when no trench was excavated are tabulated in Table 1. Also shown in this table are the estimated PPV values calculated using Equation 3 and the ratio of estimated to measured PPV. It can be observed that the frequencies corresponding to peak particle velocity are within the range of 2 to 20 Hz as noted by Mayne (1985). It can also be seen that in this monitoring programme the frequency of the peak particle velocity increases with distance.

As can be observed, while Equation 3 has underestimated PPV at close distance (by 31% at 10 m and by 14% at 15 m), it has been able to safely estimate PPV at other distances. The underestimations at 10 m and 15 m are not of major concern as they are still above what would be deemed as not causing damage (Siskind et al, 1980). Underestimation at 20 m is approximately 9% but the predicted values become overestimation of 63% at 40 m.

Table 1: Vibration monitoring summary without the trench

Distance (m)	Frequency (Hz)	PPV (mm/s)		Ratio of estimated to measured PPV
		Measured	Estimated	
10	10.6	65.0	44.9	0.69
15	12.4	33.5	28.7	0.86
20	13.1	22.9	20.9	0.91
25	15.0	14.0	16.4	1.17
30	22.2	10.7	13.4	1.25
35	24.3	7.2	11.3	1.57
40	22.2	6.0	9.8	1.63

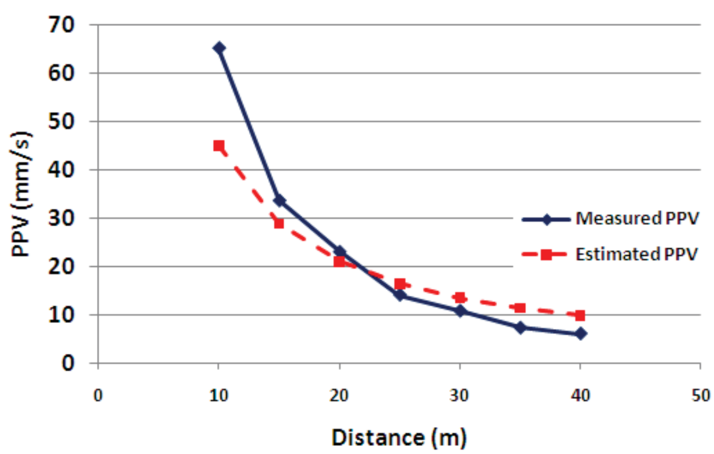


Figure 3. Comparison of measured and estimated PPV

Figure 3 compares measured and estimated PPV versus distance for the case of vibration monitoring without an isolation trench in graphical form. Noting that PPV is dependent on a number of parameters other than pounder weight, drop height, and distance, such as number of pounder drops (thus soil density), the reliability of Equation 3 can be deemed as satisfactory as a starting point.

2.3.2 Vibration monitoring with an isolation trench

Measured PPVs and their corresponding frequencies are tabulated in Table 2 for different distances and drop heights for the case when a trench was excavated. Also presented in the same table are the estimated PPVs had there been no trench.

The ratio of estimated PPV (without a trench) to measured PPV for two cases of monitoring with and without an isolation trench have also been included in Table 2. It can be seen that the ratio of estimated to measured PPV is considerably higher for the case when a trench has been excavated. For example at the distance of approximately 35 m the ratio of estimated to measured PPV is 1.57 without a trench but 2.91 and 5.46 when a trench has been excavated. The ratios of estimated to measured PPV for the trenched case is not demonstrative of the true efficiency of the trench as this ratio was also not unity when there was no trench. To obtain a more accurate estimation of the efficiency of the trench it is more proper to calibrate the results by dividing the ratios of estimated to measured PPV (last column in Table 2).

Table 2: Vibration monitoring summary with the isolation trench

Distance (m)	Drop height (m)	Frequency (m)	PPV (mm/s)		Ratio		
			Measured (trench at 13.3 m)	Estimated without trench	Estimated to measured		trenched to no trench
					trenched	no trench	
10.0	5	5.2	35.6	19.7			
10.0	8	10.0	47.2	25.5			
16.3	8	18.2	7.4	14.9	2.02	0.86	2.35
25.8	12	16.5	5.7	11.3	1.97	1.17	1.69
25.8	15	18.9	7.9	12.7	1.61	1.17	1.38
30.8	12	24.3	3.2	9.3	2.89	1.25	2.31
30.8	15	24.3	3.7	10.5	2.83	1.25	2.26
35.8	10	28.4	1.3	7.1	5.46	1.57	3.47
35.8	12	23.2	2.7	7.9	2.91	1.57	1.85
35.8	18	22.2	5.7	9.8	1.72	1.57	1.09
40.8	5	10.2	1.4	4.2	3.00	1.63	1.84
40.8	10	12.1	1.7	6.2	3.62	1.63	2.22

The division of the ratios indicates that the trench has indeed been efficient with PPV having possibly been 1.09 to 3.47 times more had there not been any trench. Graphically presenting the trench efficiency, Figure 4 shows that while the data scatter does not allow us to make a conclusive interpretation of any specific trend of the PPV reduction factor, it can still be observed that the best linear fit is almost a horizontal line with an average value of 2.05.

3 CONCLUSION

Peak particle velocity generated during dynamic replacement has been measured for two cases of having excavated a trench and without a trench. In the case where no trench was excavated measured PPV was in good agreement with the equation proposed by Hamidi et al. (2011b). Although PPV was underestimated at close distances, the estimated values still had enough accuracy to allow the engineer to make a judgement call on the need to implement specific vibration reduction measures.

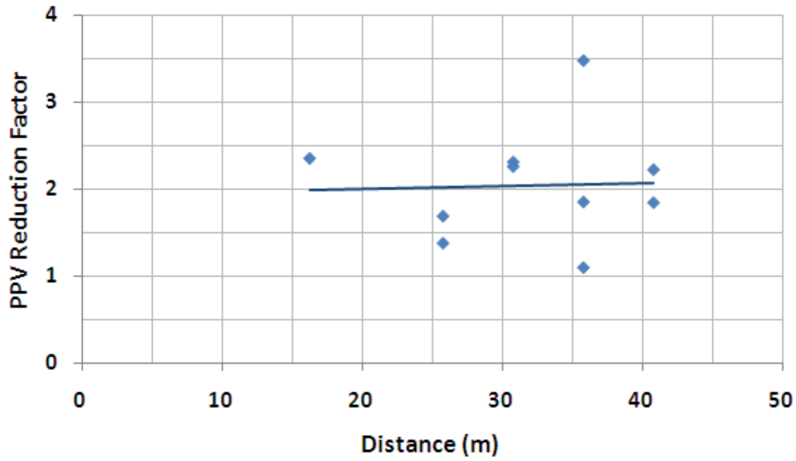


Figure 4. PPV reduction factor when using a vibration reduction trench

Excavation of a trench, 2.5 m deep (to groundwater level) was able to reduce PPV with an average reduction factor of approximately 2; thus demonstrating the effectiveness of digging trenches as vibration isolators.

4 ACKNOWLEDGEMENTS

The authors would like to express their gratitude and appreciation to Menard for providing the data that has been used in this paper.

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