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Application of Mammoth Vibro-Tamper (MVT) for the shallow compaction at airport runway expansion project in Florida

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ABSTRACT

At the runway expansion project in the Fort Lauderdale-Hollywood International airport in Florida (FLL project), there are complicated geotechnical issues that lots of cavities in the limestone-loose sand mixed ground are existing in the shallow area. The Broward County Aviation Department (BCAD), the owner of the project, has required to collapsing the cavities and compacting the runway foundation to secure the take-off and landing of aircrafts. Mammoth Vibro-Tamper (MVT) was proposed and accepted as the alternative to the originally specified Deep Dynamic Compaction (DDC) for the runway with its length of 2.4km and area of 477,000 m^2. In this report, the shallow compaction effect and vibration reduction effects by MVT are presented in comparison with the DDC.

Keywords: Airport, Densification, Shallow compaction, Ground improvement

1 INTRODUCTION

MVT was developed by Fudo Tetra Corporation in 1960's and has been widely used in Japan (more than 12,000,000 m^2) and the U.S. It is capable of compacting up to approximately 5m in depth by using a heavy steel plate (3m x 3m) and a strong vibrator (V-180, 10Hz) on top of the plate with specified duration.

FUDO Construction Inc. (FUDO) has been involved in the densification work by MVT for the For Lauderdale Airport Project (the name of contract is WP302, Figure 1) as a subcontractor to Odebrecht - Central Florida Equipment, JV (OCJV) from June, 2012 to February, 2014. The Dynamic Compaction (DDC) was originally specified as the compaction method; however, FUDO has proposed the application of MVT to reduce the vibration risk and it was accepted by the BCAD and OCJV (Figure 2). The compaction work was completed in February 2014, without causing any delay and troubles for the residual settlement due to the high embankment (H=60ft=18m).

Throughout the precise test trials, the improvement method and their quantities have been changed as shown in Table 1 and Table 2. At first, Vibro-Rod (VR) method was proposed for the area where the improvement depth was 20 feet. However through the in-situ testing, it was changed to use the combined method of MVT and the Stone Columns that were allocated beneath the MVT. At this revised application, the Stone Columns had the function of supporting all the upper loads while MVT functioned as the load transfer platform. The productivity of 1-rig operation by MVT was approximately 1,670 m^2 per 10-hour shift.

Table 1 Initial work volume

Depth	Spec.	Proposed method	Improved area
-3m (-10ft)	Dr>70%	MVT (90sec)	376,800 m^2
-6m (-20ft)	Dr>75,80%	VR	165,100 m^2

Table 2 Final work volume

Depth	Spec.	Proposed method	Improved area
-3m (-10ft)	Dr>70%	MVT (120sec x2)	311,500 m^2
-6m (-20ft)	Ave. Dr>70%	MVT (90sec x2)	163,100 m^2
	3.65m spacing	Stone Column	

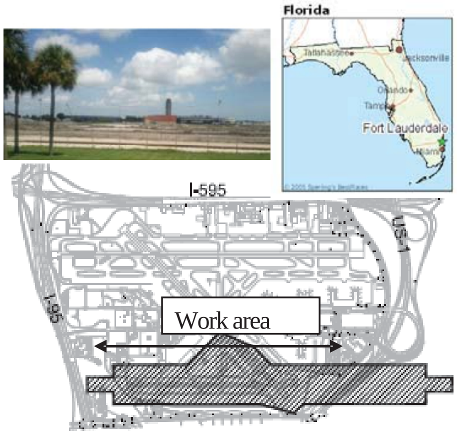


Fig. 1 Location of the airport

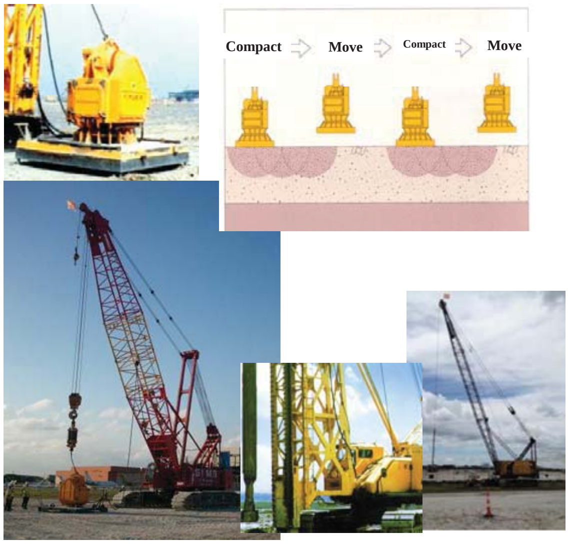


Fig. 2 MVT, VR, DDC methods

Boring data along the runway are shown in Figure 3 (RW- means the each boring location). In some area at West half of the runway, small cavities (approximately 25 cm in diameter) existed among the subsurface soils and were covered by the shell type hard limestone (Figure 4), whereas grains of porous oolitic limestone with 5 to 8 cm in diameter were deposited at 6m depth in some area at East half of the runway. Figure 5[1)] shows the typical formation of oolitic limestone.

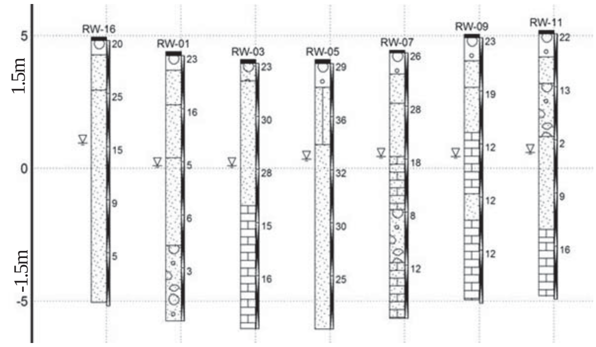


Fig. 3 Boring data along the west half of runway

Fig. 4 Small cavities

Fig. 5 Porous Oolitic Limestone [1)]

2 EFFECT OF MVT IN COMPARISON WITH DDC

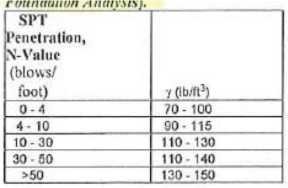
2.1 Conversion of the Required Performance Criteria (Relative density (Dr): equal to or greater than 70%)

To convert from SPT N-value to relative density, the following formula (Meyerhof's formula[2)]) has been applied, and to decide the effective overburden pressure, the Bowles's correction[3)] has been used (Table 3).

$$\mathrm{Dr} = \sqrt{\frac{N}{17 + 11.8\sigma_v'}} \times 100(\%) \ldots\ldots Eq(1)$$

Where, σ_v' is the effective overburden pressure (ksf, 1ksf=48.9kPa).

Table 3 Bowles relationship[3)]



SPT Penetration, N-Value (blows/ foot)	γ (lb/ft^3)
0 - 4	70 - 100
4 - 10	90 - 115
10 - 30	110 - 130
30 - 50	110 - 140
>50	130 - 150

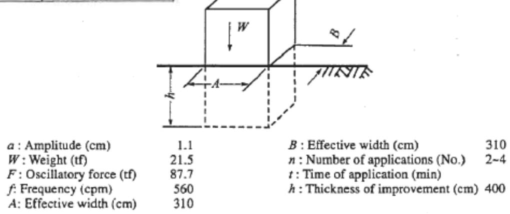
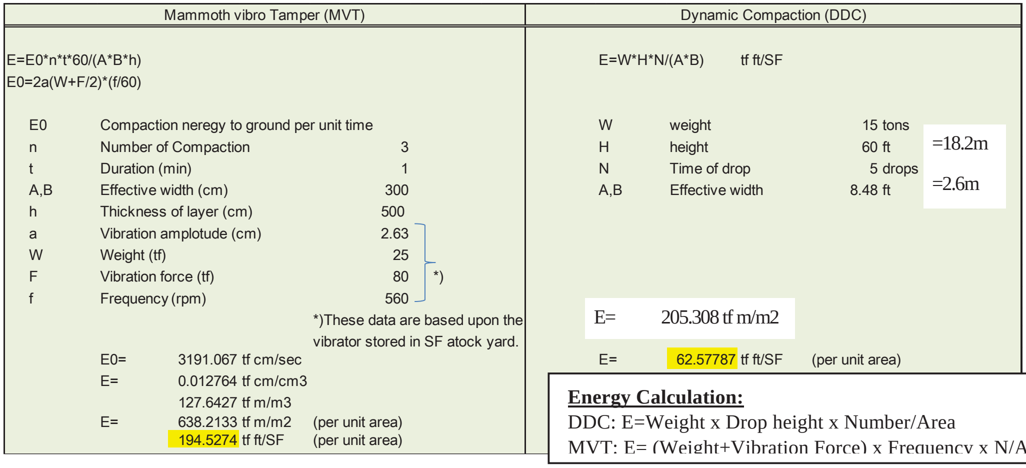


Fig. 6 Energy calculation for MVT [4)]

Table 4 Comparison of energy level between MVT and DDC



Mammoth vibro Tamper (MVT)				Dynamic Compaction (DDC)			
E=E0*n*t*60/(A*B*h)				E=W*H*N/(A*B)	tf ft/SF		
E0=2a(W+F/2)*(f/60)							
E0	Compaction neregy to ground per unit time			W	weight	15 tons	
n	Number of Compaction	3		H	height	60 ft	=18.2m
t	Duration (min)	1		N	Time of drop	5 drops	
A,B	Effective width (cm)	300		A,B	Effective width	8.48 ft	=2.6m
h	Thickness of layer (cm)	500					
a	Vibration amplotude (cm)	2.63	*)				
W	Weight (tf)	25					
F	Vibration force (tf)	80					
f	Frequency (rpm)	560					
		*)These data are based upon the vibrator stored in SF atock yard.		E=	205.308 tf m/m2		
	E0=	3191.067 tf cm/sec		E=	62.57787 tf ft/SF	(per unit area)	
	E=	0.012764 tf cm/cm3					
		127.6427 tf m/m3					
	E=	638.2133 tf m/m2	(per unit area)				
		194.5274 tf ft/SF	(per unit area)				

Energy Calculation:

DDC: E=Weight x Drop height x Number/Area

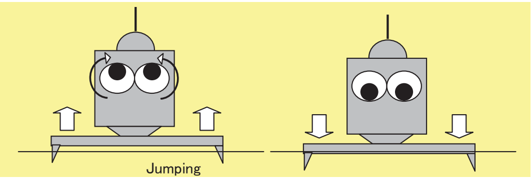
MVT: E= (Weight+Vibration Force) x Frequency x N/Area

2.2 Comparison between MVT and DDC in surface energy calculation

Table 4 shows the comparison of vibration surface energy level by MVT and DDC. For the estimation of MVT energy level at the ground surface, Tanimoto's formula[4)] was revised to apply for energy level at unit area (Figure 6).

Murayama and Tanimoto[5)] have indicated that the following 'Compaction factor' α is the key factor for the plate compaction and higher densification will be achieved in the case of α<1 (see Figure 7).

Thus, it is easy to suppose that the vibration plate will be jumped in the case of α<1. In case of MVT, the α value is approximately 0.31, so this causes high energy and performance of MVT consequently.



α = (Dead weight) / (Vibration force)

= 25ton / 80ton = 0.31 (for MVT)

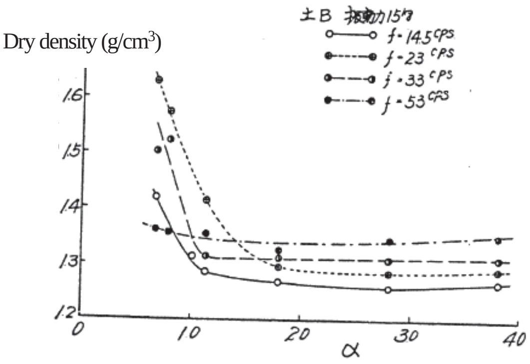


Fig. 7 Effect of α (Murayama & Tanimoto[5)])

According to the Table 4, energy level of MVT (1-minute x 3-times) is approximately 3.1 times larger than that of DDC (15-ton weight is dropped five times from 60ft (18.3m) height. This is regarded the greater DDC specification in the U.S. due to its limit of equipment capacity.

In this airport project, at another ground compaction contract on adjacent area (the name of contract is WP304/305), DDC has been applied from Aug. 2013 to Jan. 2014. From the Public Record Request, the DDC results (increase of SPT-N value) were investigated and compared with MVT results. The comparison results have indicated that MVT is much more effective than DDC under the condition of same energy level.

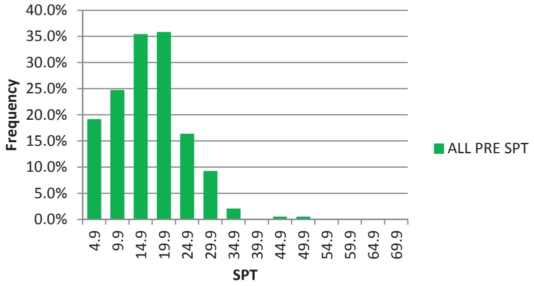


Fig. 8 Frequency of SPT data in original ground (depth up to 15ft) Average N=13.5

Table 5 Specification of test trial for DDC (WP304/305), 1FT=0.3044m

			First Round (Aug-2 to Aug-21)				2nd Round (Aug-22 to Aug-25)		
	Weight (ton)	Height (ft)	Spacing (FT)	Effective area (SF)	Number of Drop (N)	Energy (tf ft/SF)	Spacing (FT)	Effective area (SF)	Energy (tf ft/SF)
Grid#1	15	60	15.0	225.0	5	20.0	7.5	56.25	80.0
Grid#2	15	60	10.6	112.4	5	40.0			
Grid#3	15	60	8.5	71.9	5	62.6			
Grid#4	15	60	10.6	112.4	10	80.1			
Grid#5	15	60	10.6	112.4	5	40.0			
Grid#6	15	60	10.6	112.4	5	40.0			
Grid#7	15	60	10.6	112.4	5	40.0			

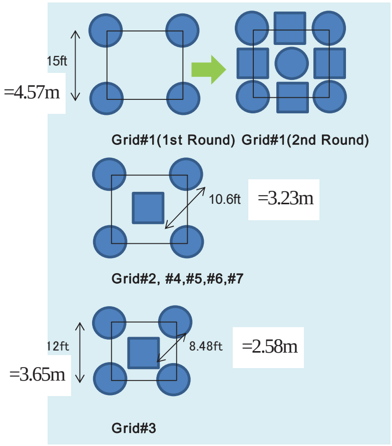


Table 6 Comparison between DDC and MVT , 1FT=0.3044m

	Spacing (FT)	Effective area(SF)	Number of Drop	Energy (tf ft/SF)	Average SPT-N	Fail Rate (%)
DDC Grid#1-1	15.0	225.0	5	20.0	12.9	42.1%
DDC Grid#1-2	7.5	56.3	5	80.0	18.0	30.4%
DDC Grid#2	10.6	112.4	5	40.1	17.9	18.3%
DDC Grid#3	8.5	71.9	5	62.6	19.3	11.6%
DDC Grid#4	10.6	112.4	10	80.0	22.9	6.9%
DDC Grid#5,6,7	10.6	112.4	5	40.1	16.3	20.5%
DDC Grid#8	8.5	71.9	5	62.6	15.4	20.0%
DDC Grid#22,23,24,27,29	8.5	71.9	5	62.6	15.2	32.7%
MVT tamp No Trench				194.0	25.6	9.7%

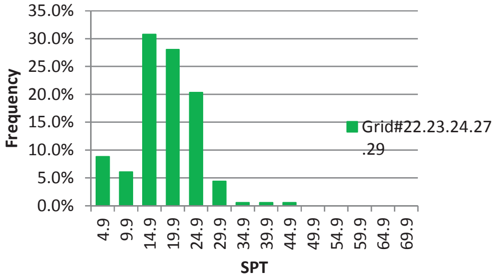


Fig. 9 SPT after DDC (Ave, N=15.2)

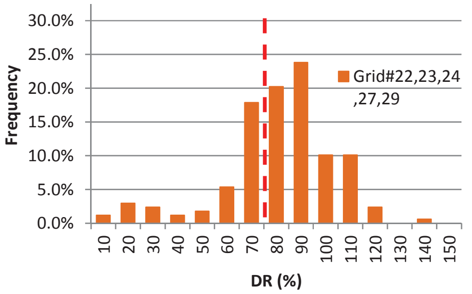


Fig. 10 Dr (Relative density) after DDC (FAIL rate: 32.7%)

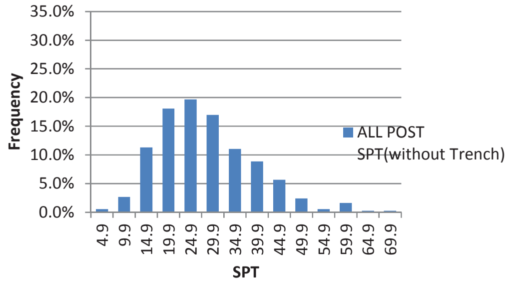


Fig. 11 SPT after MVT (Ave. N=25.6)

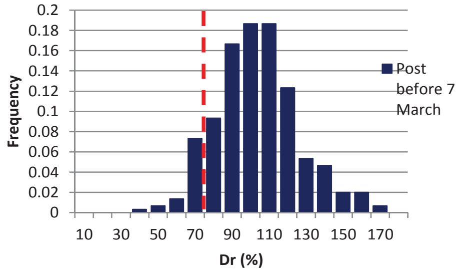


Fig. 12 Dr (Relative density) after MVT (FAIL rate: 9.7%)

Figure 8 is the frequency distribution of SPT-N value of the original ground before densification up to 15ft (=4.6m) depth. Table 5 shows the test trial specification of DDC. At the Grid#1, due to the unsuccessful results of DDC performance by the initial specification, additional dropping was performed in-between the initial dropping locations.

Table 6 and Figure 9 through Figure 13 present the results of DDC and MVT (west half of the runway, without trenching). By the higher average SPT-N value and lower Fail rate of MVT in comparison with DDC, MVT is regarded more effective than DDC. Fail rate is defined as the number of Dr (relative density) that is lower than 70% divided by the total number of Dr.

Furthermore, the relationship between the energy level calculated by using Table 4 and the average SPT-N value is shown in Figure 14. At MVT method, large increase of SPT is induced through the higher compaction energy. The advantages of MVT against DDC are listed as follows.

(1) Higher densification effect with higher surface energy
(2) Higher work productivity
(3) Lower impact of vibration and noise on adjacent existing structures (Safety work)
(4) 100% improvement area coverage is achievable.

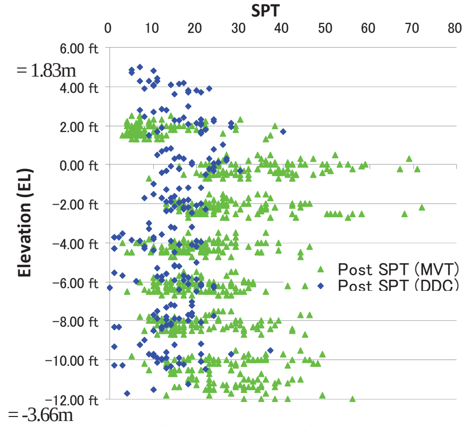


Fig. 13 Comparison between MVT and DDC (SPT-N)

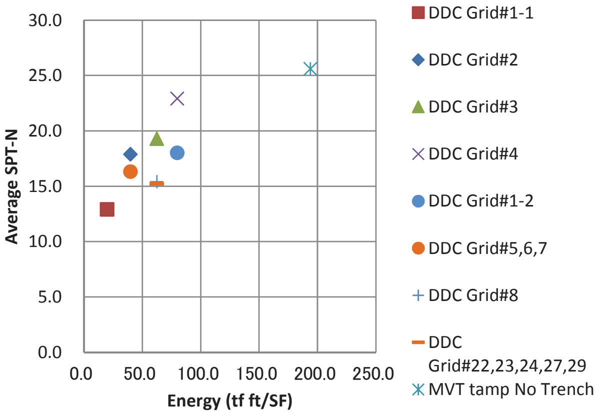


Fig. 14 Relationship between the surface energy level and average SPT-N value after improvement

As shown in the Figure 15 and Figure 16 which were obtained in this project, there is some amount of compaction effect even at 5.2m (17ft) depth which is 1.73 times of plate size 3m. The average N value was increased from 27.8 to 37.5 after the MVT tamping.

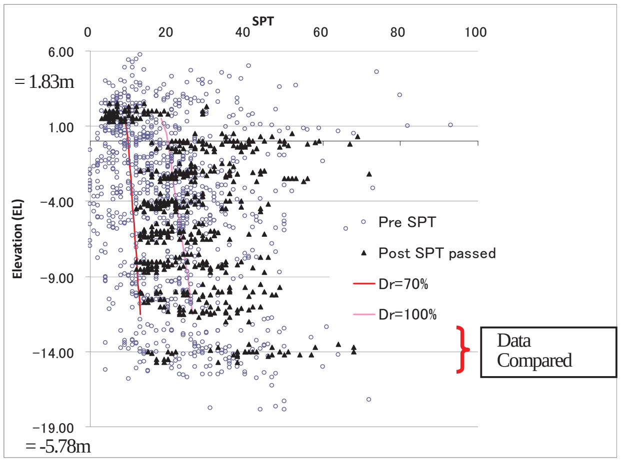


Fig. 15 Pre and post-SCP data

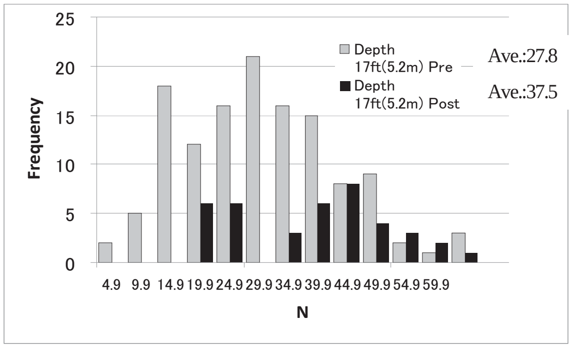


Figure 16 Comparison between Pre- and Post- data at deeper zone

3 TECHNICAL INNOVATIONS FOR MVT

3.1 Trenching and subsequent backfilling

The main reason for the above Fail (9.7% at Figure 12) at verification test is the difficulty to collapse the small cavities due to existing hard shell type limestone above the cavities. To address this issue, we have tried to apply the fracturing (trenching and subsequent backfilling) to 3.0m(=10ft) in depth and 0.9m(=3ft) in width prior to the MVT tamping in order to collapse the limestone structure (Figure 17).

As shown in Figure 18 and 19, the fracturing was very effective to assist the compaction by MVT and consequent increase of SPT.

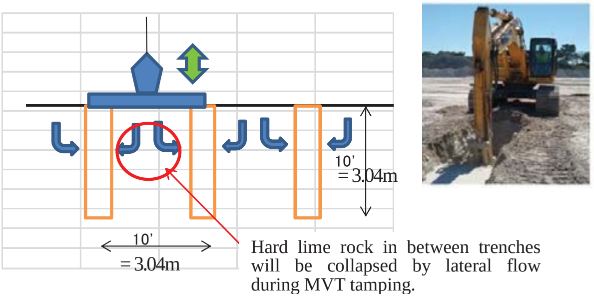


Fig. 17 Trench and the tamping effect

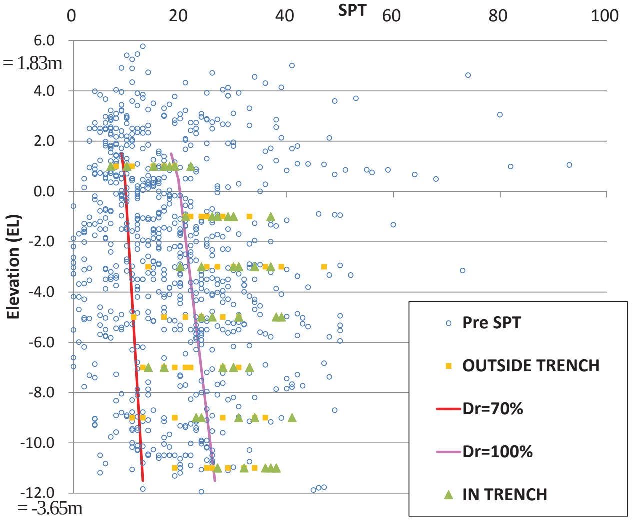


Fig. 18 Increase of SPT-N value after MVT with trenching

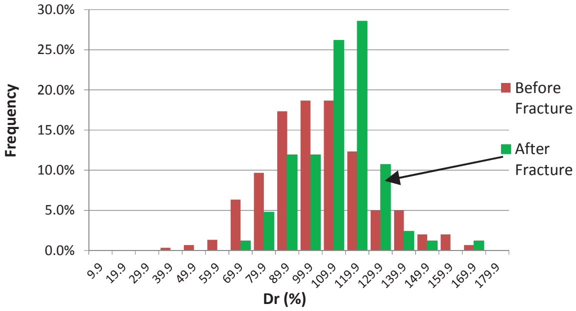


Fig. 19 Effect of trenching

3.2 Double MVT tamping sequence

In this project, the double tamping sequence was so effective at the area where a lot of water came up during 1st tamping (Figure 20) due to generation of excess pore water pressure with 'Dilatancy effect'. However, no water came up at 2nd tamping (Figure 21) at few hours after 1st tamping. In addition, large increase of SPT-N value was obtained after the 2nd tamping as shown in Figure 22.

The mechanism of double tamping effect is supposed as follows (Figure 23).

(1) At 1st tamping, the compaction energy is absorbed by the raised ground water, and the ground surface area is dominant to be compacted.

(2) At 2nd tamping, since surface area has been already compacted, deeper zone is densified by the vibration force.

Fig. 20 1st tamping (Lot of water comes up)

Fig. 21 2nd tamping (No water comes up)

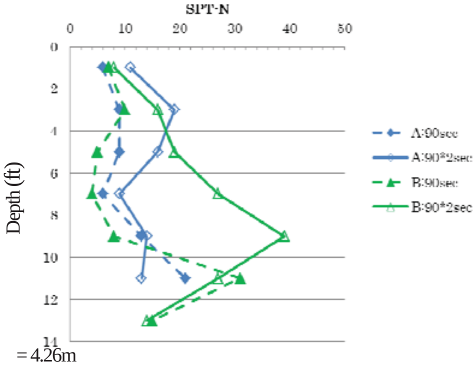


Fig. 22 Effect of double tamping

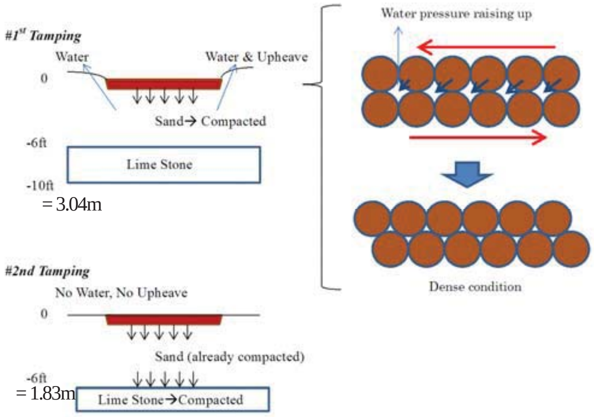


Fig. 23 Mechanism of double tamping

4 THE VIBRATION REDUCTION EFFECT

Figure 24 through 26 shows the vibration level with the distance from vibration source. Approximately 40ft (=12.2m) distance from MVT equipment makes it possible to secure the criterion (velocity, ppv: less than 1.25cm/sec).

Moreover, at the trial performance of MVT, vibration isolation trench with 4ft depth at 70 feet (=21.3m) distance are installed at the south side. The vibration reduction effect was approximately 0.38 cm/sec.

Figure 26 shows the comparison of vibration level between DDC and MVT, and obviously the vibration impact of DDC is much larger than MVT at the area of less than 150 feet distance from the equipment.

Fig.24 Vibration monitoring

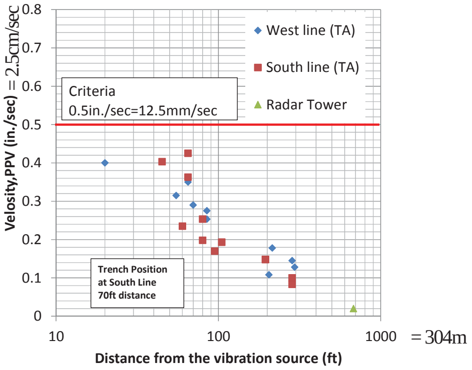


Fig. 25 Vibration of MVT and trench effect

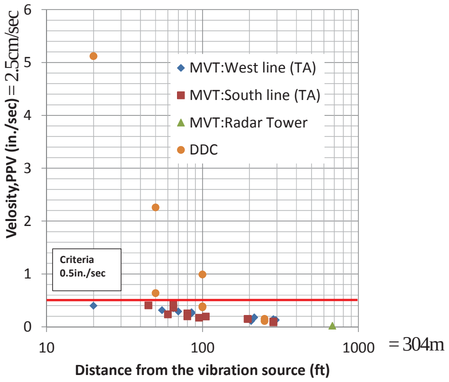


Fig. 26 Comparison of vibration level

5 CONCLUSIONS

In this project, several advantages of MVT have been discovered again and some technical innovations have been introduced.

In regard to the shallow compaction, the ‘Compaction factor: α’ is the key index. It should be less than 1.0 which means the vibration force is beyond the dead load so that plate will be jumped up during the vibration. This causes the greater compaction effect consequently.

REFERENCES

1) L.A. Prieto-Portar, Elastic and Strength Properties of Calcareous Rocks of Dade County, Florida, *ASTM special technical publication* 1983.
2) Mayerhof, G.G. 1957. Discussion on Research on determining the density of sands by penetration testing, *Proc. 4th Int. Conf. on Soil Mech. And Found. Engrg.*, Vol.1: 110
3) J.E.Bowles, 1977. Foundation Analysis and Design, Fourth Edition, McGraw-Hill Book Company.
4) Tanimoto, K, 1958. Basic study regarding the soil compaction by surface vibration, Doctoral thesis in Kyoto University
5) Murayama, S., Tanimoto, K. and Matsuno, S., 1957. Experimental study regarding compaction induced vibration for confined soil, *Journal of Japan Society of Civil Engineers*, No.43, pp.55-59. (in Japanese)