Analytical Study on Behaviour of Soil-Footing Interaction under Machine Loading

Mohit Verma,(M-Tech), Guru Nanak Dev Engineering College, Ludhiana, India & Executive Engineer, Punjab Water Supply and Sewerage Board, Chandigarh, India
K.S Gill, Professor, Guru Nanak Dev Engineering College, Ludhiana, India.
Parshant Garg, Asstt. Professor, Guru Nanak Dev Engineering College, Ludhiana, India.

Abstract

Every structure's load is transferred to soil by base of structure called foundation. In general, foundation carries various types of loads like self weight of the structures, live load, wind load, earthquake load, Machine loads, etc. These loads are basically of two types in nature, one is Static load another is dynamic load. Static loads do not change their magnitude and on other side dynamic loads are fluctuating their magnitude varies with time so the behaviour of footing under static load and dynamic load is entirely different.

In a foundation system soil and foundation act as a single body. When a harmonic periodic load is applied on a foundation by a machine mounted on it. The machine foundation and soil in the vicinity to the foundation act as a single medium. The vibration of machine loading is distributed in the soil by the foundation. This principle is called soil interaction.

The effect of dynamic load is not limited only to the soil in vicinity of the machine foundation. However if some structure or independent foundation is present near the machine foundation it also experience dynamic effect of the machine foundation near to it. Sometimes it has seen major changes in the structure in vicinity to machine foundation has been noticed which are main reasons for damages like tilting of nearby structure, cracks in plinth protection, foundation settlement, etc.

In the current study effect of dynamic loading on a footing and effect on nearby secondary footing is studied for this purpose first of all the analytical studies are carried out in the PLAXIS 2D platform for the purpose of accurate and practicality of results validation of thesis work with the previous done experimental work reference from research done by **Abhijeet Swain & Priyanka Ghosh** at IIT Kanpur and published in Canadian Geotechnical Journal are taken and various are taken from their published journal. For analytical study experimental data is modelled on PLAXIS 2D platform which is analyzed on appropriate scale and same geometrical properties and same loading conditions, so that the study can be compared with the experimental results.

After validation various parameters like machine foundation and nearby structure under varying static loads, provision of sand drain/blankets between closely spaced footing under dynamic load, effect of varying amplitude force with different spacing between primary and secondary footings etc. are studied.

It has been observed that with increase in spacing between the footings, dynamic effect of loading decreases and with increase of static loading on the secondary footing also peak displacements and acceleration gets reduced. With inserting sand blanket between two footing is also beneficial in reducing dynamic displacements as coarse sand is having very good damping properties, also the effect of the variation in thickness of the blanket is more dominating then variation in length of the blanket. Also relation is developed between dynamic displacements under secondary footing for peak frequency at various L/T ratios (Length/Thickness) of sand blanket.

Keywords: Soil-Footing interaction, dynamic loading, dynamic displacement, sand blanket, damping.

1. Introduction

The basic concept of the science every action is equal to an opposite reaction. If we are constructing a structure its weight has to be taken by someone. The answer to this 'someone' is soil. Every structure's load is transferred to soil by base of structure called foundation. In general foundation carries various types of loads like self weight of the structures, live load, wind load, earthquake load, machine loads, etc. These loads are basically two type in nature one is static load another is dynamic load. Static loads does not change their magnitude, however on other side dynamic loads are fluctuating, their magnitude varies with time so the behaviour of footing under static load and dynamic load is entirely different.

Dynamic load are practically comes for machinery like motors, turbines, generator, etc which consist of unbalanced moving masses which creates various load on soil. In addition to above repeated moving vehicles on railway track, roads and bridges are also example of dynamic loading.

Main aspect of civil engineer while constructing a structure is safety of that structure and also no harm shall be caused to the nearby structure. So proper study of behaviour of machine foundation and its effect on nearby structure is important. Also the cost aspect should be considered in foundation design but no compromise shall make with the safety of structure and nearby structure. Because life is more precious than money.

The effect of dynamic load is not limited only to the soil in vicinity of the machine foundation. However if some structure or independent foundation is present near the machine foundation it also experience dynamic effect of the machine foundation near to it. Sometimes it has seen major changes in the structure in vicinity to machine foundation has been noticed, which are main reasons for damages like tilting of nearby structure, cracks in plinth protection, foundation settlement.

2. Methodology of work

The experimental parameters are obtained from previous done study by **Abhijeet Swain & Priyanka Ghosh** in IIT Kanpur based on theses parameters geometrical modelling is done on analytical platform PLAXIS and similar loading conditions are generated analytically as considered in the experiment based on the outcomes of the analytical results first obtained various other parameters like effect of varying amplitude with spacing between two footings, effect of increasing static load on primary and secondary footing, placing of sand drain between two closely spaced footing, etc will be studied by modelling various geometrical models in PLAXIS.

3. Experimental Data and setup

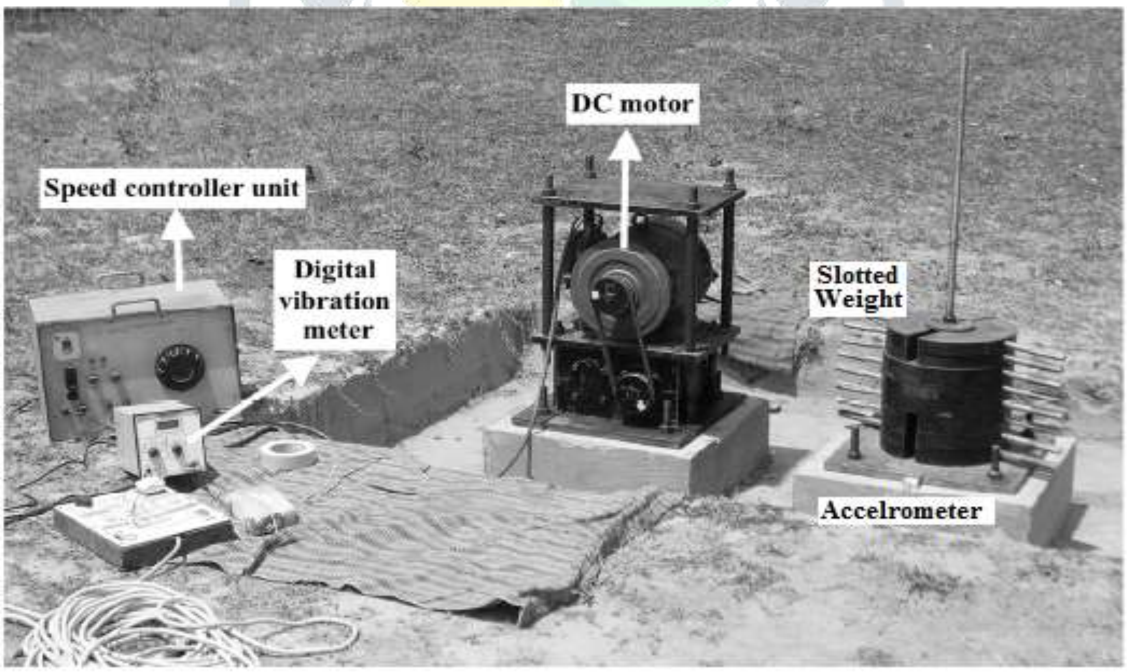
For the purpose of validation of thesis work with the previous done experimental work reference from research done by **Abhijeet Swain & Priyanka Ghosh** at IIT Kanpur and published in Canadian Geotechnical Journal are taken and various parameters like foundation properties, soil properties, static and dynamic loading condition are taken from their published journal.

Test setup created by previous researchers consist of two RCC footings of M20 grade in two size as 0.55m X 0.55m X 0.2m as primary footing on which vibration machine and oscillator is placed where on other side 0.65m X 0.65m X 0.2m as secondary footing on which circular slotted weight are placed in a pit excavated at IIT Kanpur campus area on clayey silt soil of size 1.4m X 1.4m X 0.3m size. Dynamic force is produced by means of oscillator from 1200rpm to 3000rpm. Load intensity on both footing is maintained 10.75 kN/m^2. The spacing between two footings is placed S/B ratio 0.45. The dynamic force generated by oscillator follows equation as $F_o = m_e.e.\omega^2$. Where the parameters are F_o is unbalanced force in kN and m_e is eccentric weight rotating at eccentricity e and ω frequency of vibrating machine in rpm. The test set up and parameter data is as shown below.-

Table No. 1

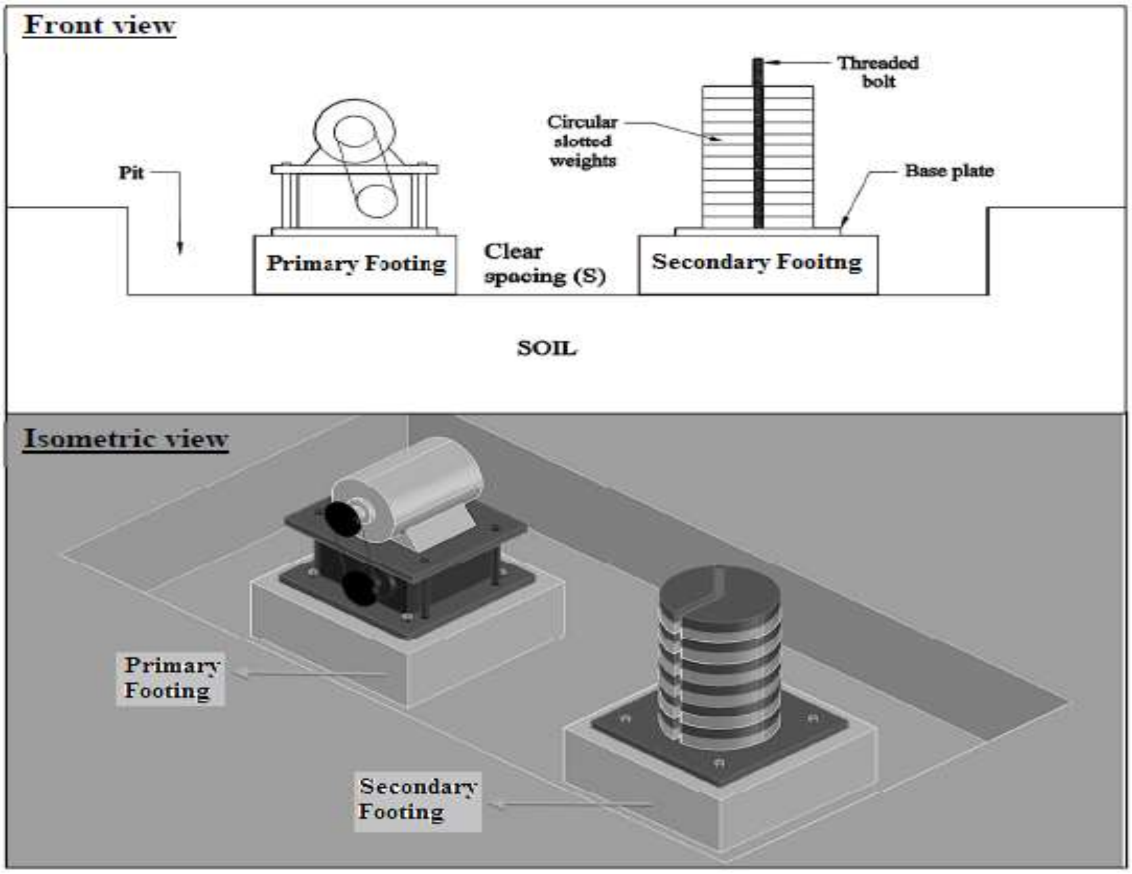
Soil and Footing Parameters details

Foooting Parameters		
Sr No	Parameter	Property
1	Primary Footing	0.55mX0.55mX0.2m
2	Secondary Footing	0.65mX0.65mX0.2m
3	Material	M20 Concrete
4	Density of Material	24 kN/m^3
5	Clear Spacing	0.25m (S/B = 0.45)
6	Static Loading	10.75kN/m^2
7	Motor Speed	1200rpm to 3000rpm
		(3.5 Hz to 8.0 Hz)
Soil Parameters		
Sr No	Parameter	Property
1	Soil Type	Clayey Silt up to depth 2m
2	Liquid Limit	35%
3	Plasticity Index	17%
4	γ_{sat}	17.5 kN/m^3
5	γ_{dry}	16.0 kN/m^3
6	E_s	20000 kN/m^2
7	K_x	1.15X10^{-6} m/sec
8	K_y	1.15X10^{-6}m/sec
9	K_s	25000
10	υ	0.35



View of experimental Setup

Figure No. 1



Layout of two closely spaced footings

Figure No. 2

4. Validation of work

PLAXIS is computer based platform on which whole study about behaviour of soil under various dynamic loading is to be studied the results or outcome of the software depends on input provided to it. To be more realistic and have practical results which can be correlated and useful to practical implementation in engineering the result first should be compared with similar problem being previously done using experimental method (Physical Method). So that after comparing the result obtained from PLAXIS with experimental result the work could be validated and based on outcome various other parameters of soil and foundation interaction under dynamic loading can be worked on using analytical approach (PLAXIS).

Table No. 2

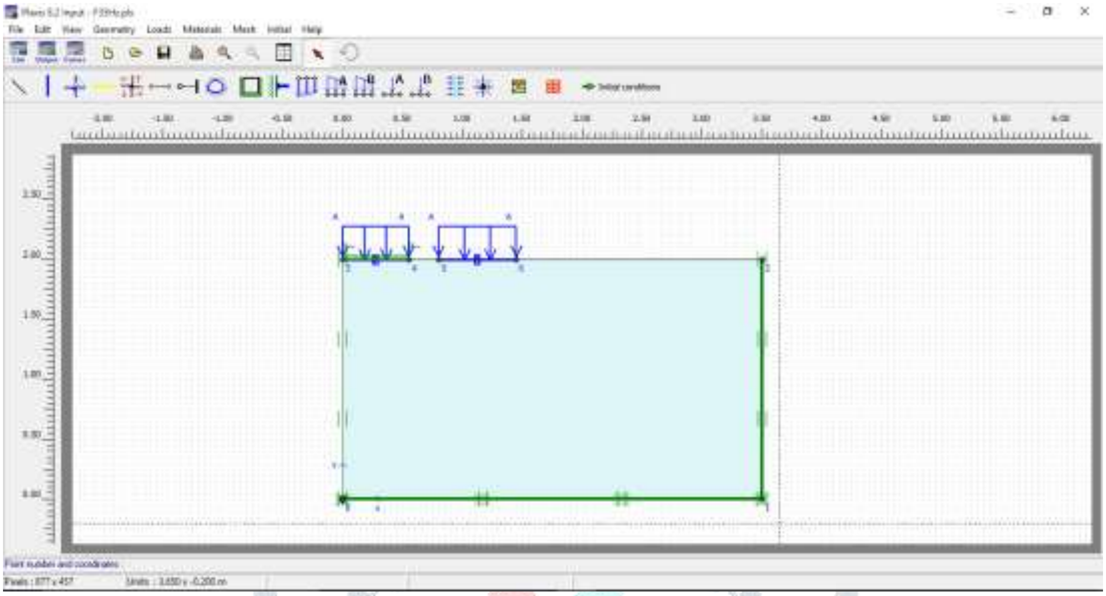
Comparison of experimental and analytical results

Sr No	Force (m.e)	Experimental Result Displacement(10E-6m)				Analytical Result Displacement(10E-6m)			
		Resonant Frequency (Hz)	Resonant Frequncy (rpm)	Primary Footing	Secondary Footing	Resonant Frequency (Hz)	Resonant Frequncy (rpm)	Primary Footing	Secondary Footing
1	0.017	6.35	2300	128	121	6.5	2450	114.8	73
2	0.025	6.15	2200	210	170	6.5	2450	208	150
3	0.033	6.05	2100	272	220	6.5	2450	265.5	179.5

5. Computational work

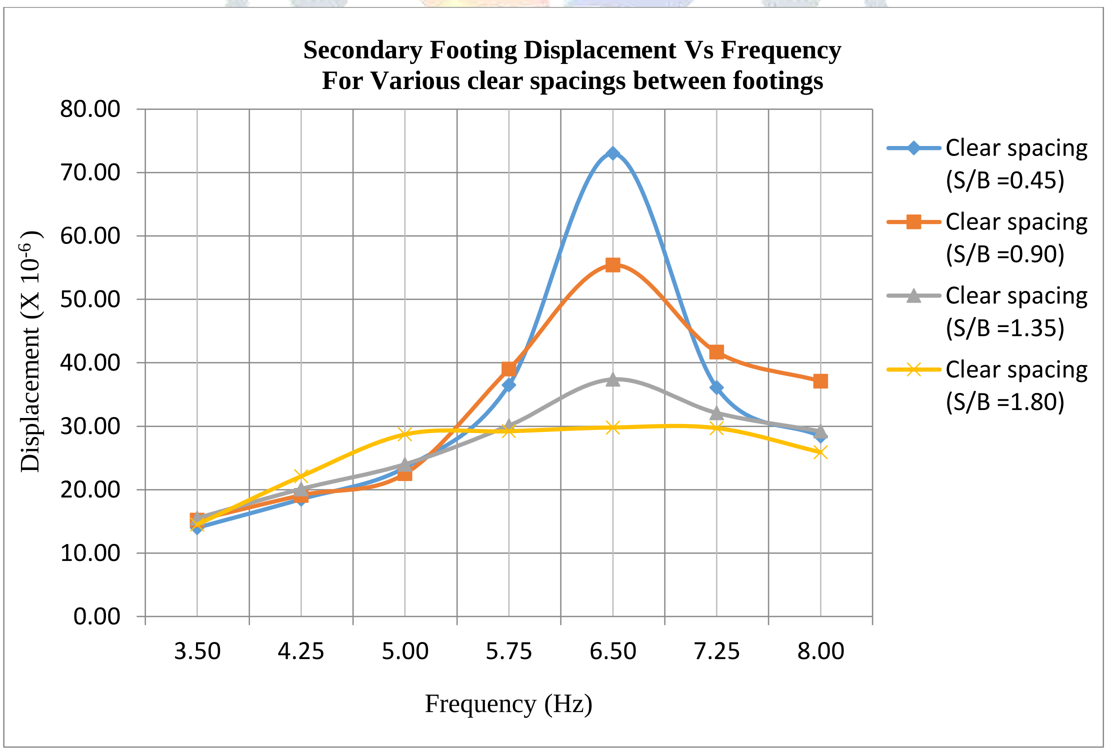
Effect of varying spacing between footings

In this case secondary footing is modelled in four different spacing between primary footing and secondary footing. i.e. S/B ratio 0.45,0.90,1.35,1.80 where as S/B is the ratio of clear distance between edge of footings to width of the primary footing. Dynamic load is kept variable for each spacing case from 3.5 Hz to 8.00 Hz (Based on experimental study) various geometric models



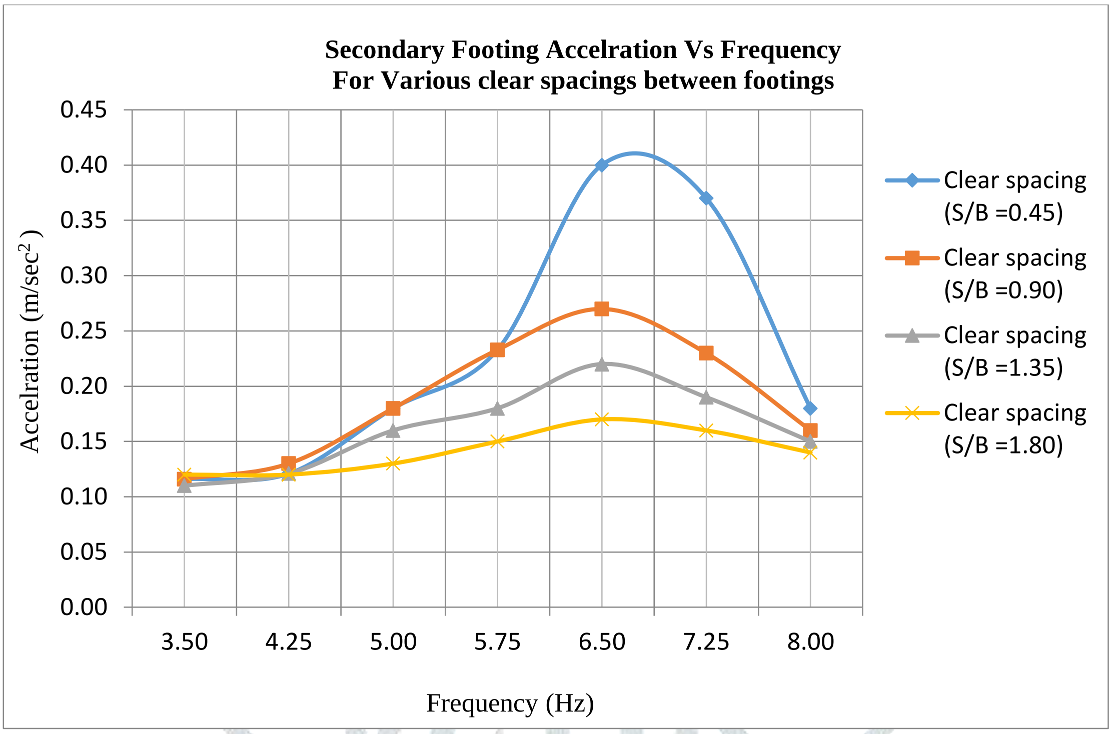
Geometrical Model for varying spacing between footings

Figure No. 3



Displacement Vs Frequency for Various Clear spacing between footings

Figure No. 4

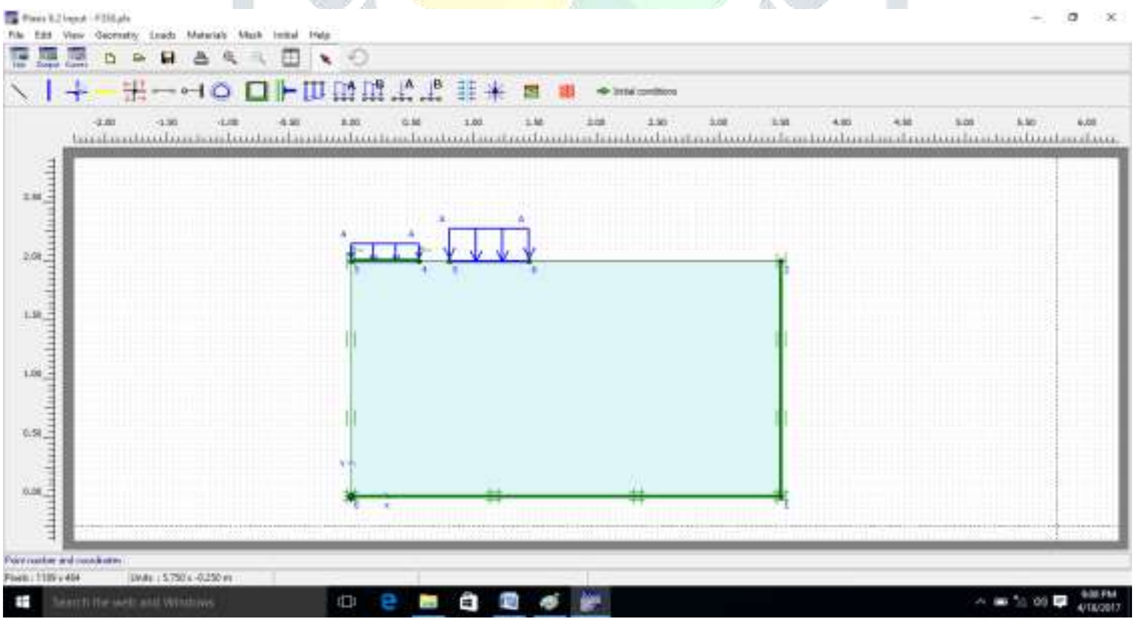


Acceleration Vs Frequency for Various Clear spacing between footings

Figure No. 5

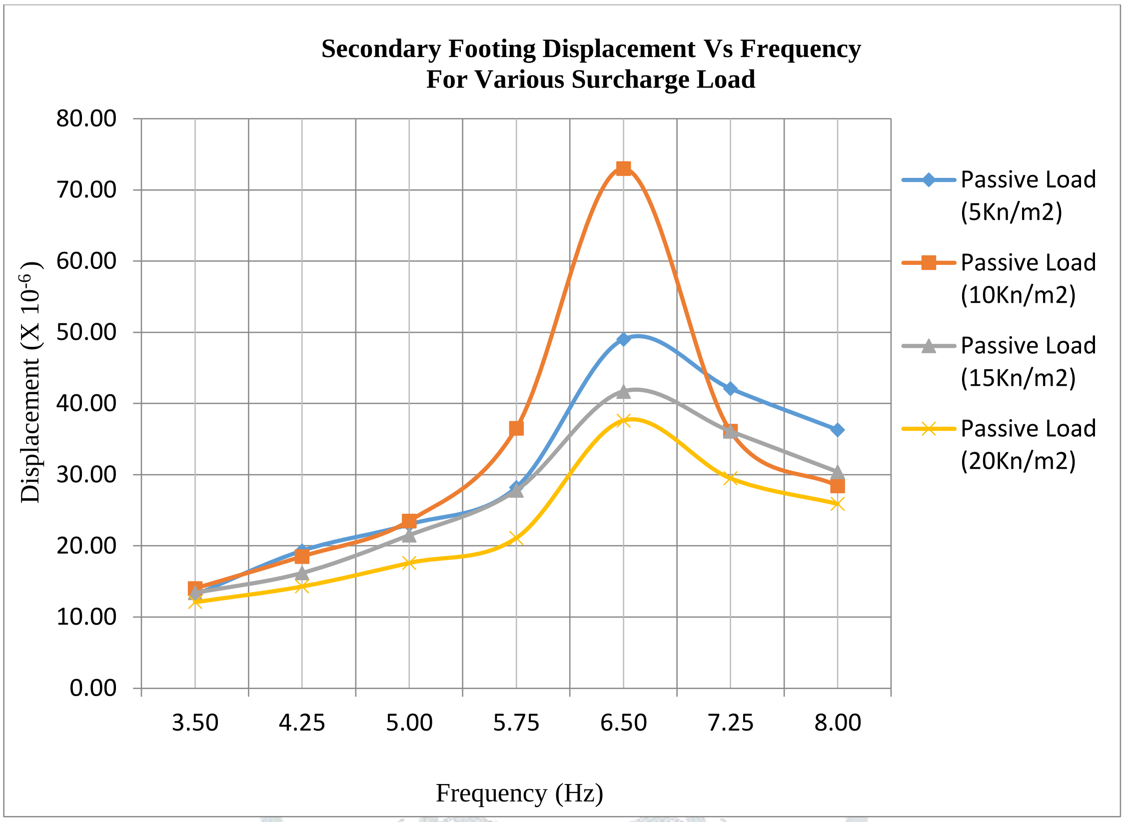
Effect of varying surcharge pressure on secondary footing

In this case primary footing is modelled with fixed static load (10 kN/m^2) whereas secondary footing is loaded with four different static loading. i.e. 5 kN/m^2,10 kN/m^2,15 kN/m^2 & 20 kN/m^2 .S/B ratio is kept constant as S/B = 0.45 to observe trend of secondary footing under different surcharge pressure. Dynamic load is kept variable for each loading case from 3.5 Hz to 8.00 Hz (Based on experimental study) various geometric models



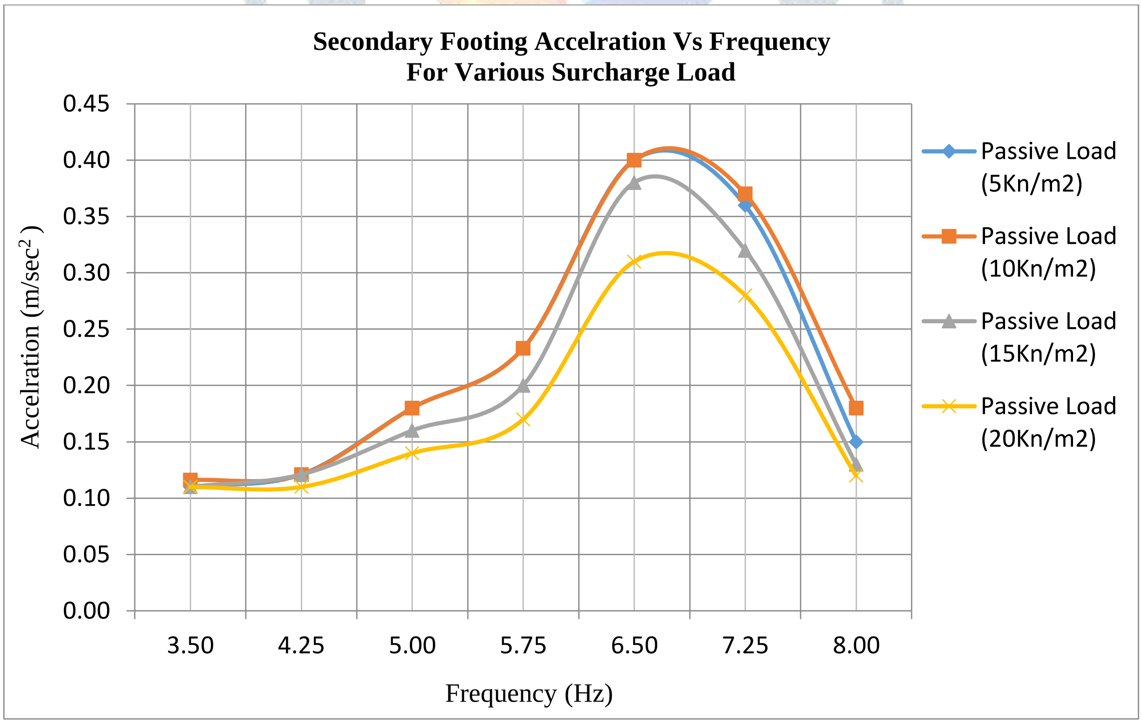
Geometrical Model for varying surcharge pressure on secondary footing

Figure No. 6



Displacement Vs Frequency for various surcharge load on secondary footing

Figure No. 7



Acceleration Vs Frequency for various surcharge load on secondary footing

Figure No. 8

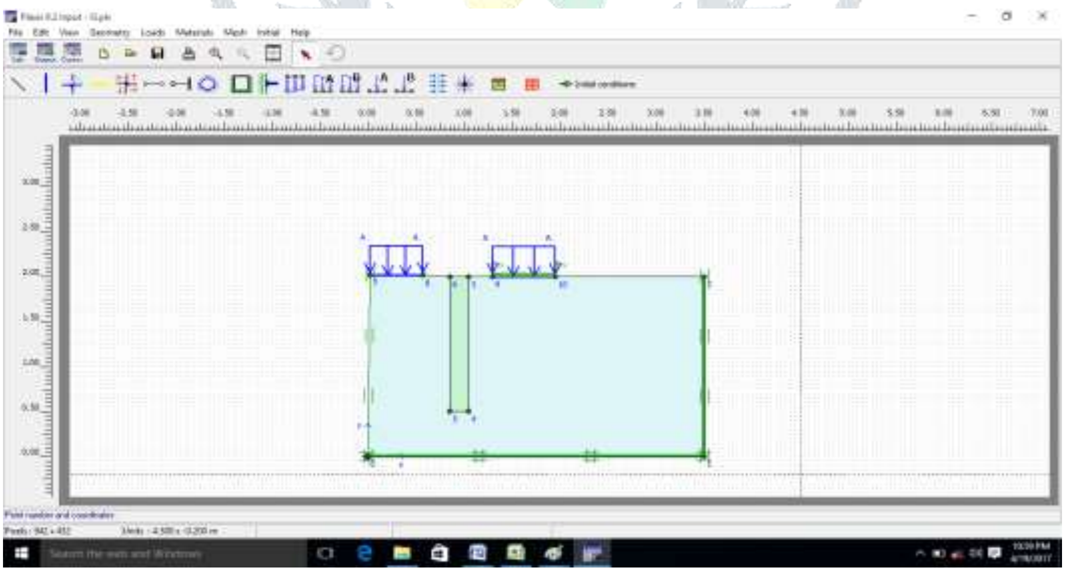
Effect of installing sand blanket between footings

Sand is a coarse material which offers very good damping properties in soil medium. Harmonic sinusoidal wave from dynamic soil can be suppressed with use of intermediate sand drains or blanket. In current work sand blanket is introduced in different combinations of length and thicknesses and the effect after using sand blanket between primary and secondary footing is studied. The properties of sand medium and various length and thickness combinations are as follows. Studies are done in two way keeping length constant and varing thickness of blanket variable and vice versa.

Table No. 2

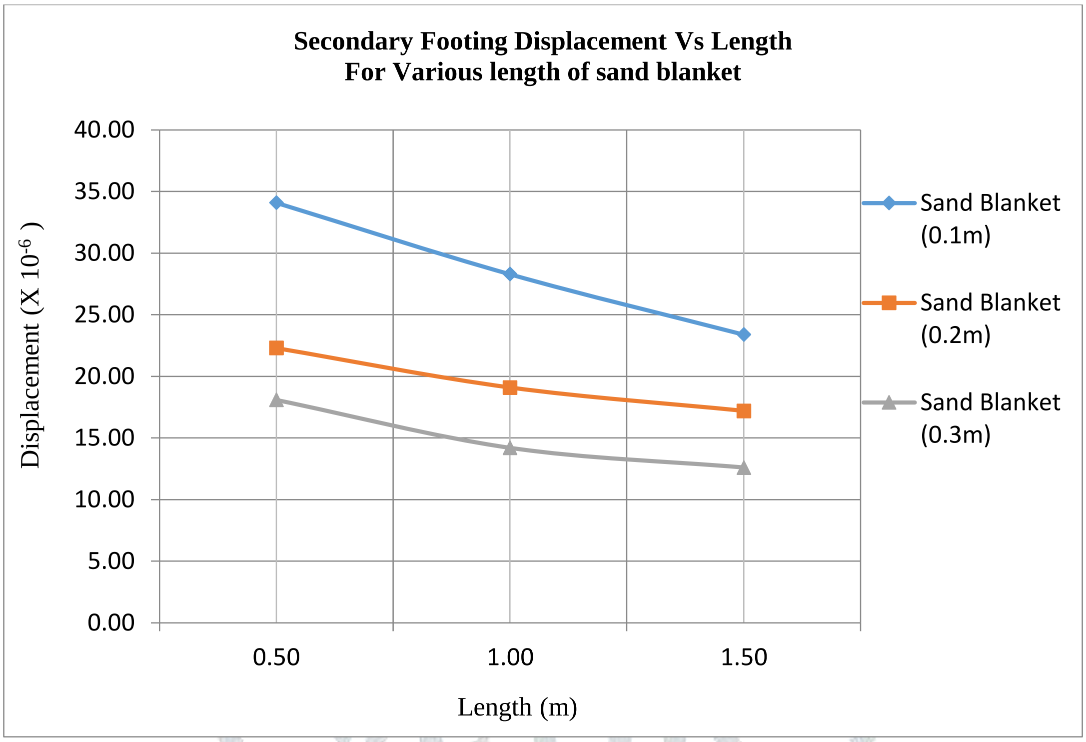
Coarse sand geometric case for sand blanket study

Coarse Sand Properties					
Sr No	**Parameter**	**Property**			
1	γ_{sat}	20 kN/m^3			
2	γ_{dry}	17 kN/m^3			
3	K_x	1.5X10^{-4} m/sec			
4	K_y	1.5X10^{-4} m/sec			
5	E_s	18000 kN/m^2			
6	υ	0.3			
7	Φ	30°			
8	Reileigh α	0.9			
9	Reileigh β	0.6			
Geometric case of varing length of sand blanket					
Sr No	**Parameter**	**Thickness(m)**	**Length1**	**Length2**	**Length3**
1	Thickness	0.10	0.50	1.00	1.50
2	Thickness	0.20	0.50	1.00	1.50
3	Thickness	0.30	0.50	1.00	1.50
Geometric case of varing thickness of sand blanket					
Sr No	**Parameter**	**Length(m)**	**Thickness1**	**Thickness2**	**Thickness3**
1	Length	0.50	0.10	0.20	0.30
2	Length	1.00	0.10	0.20	0.30
3	Length	1.50	0.10	0.20	0.30



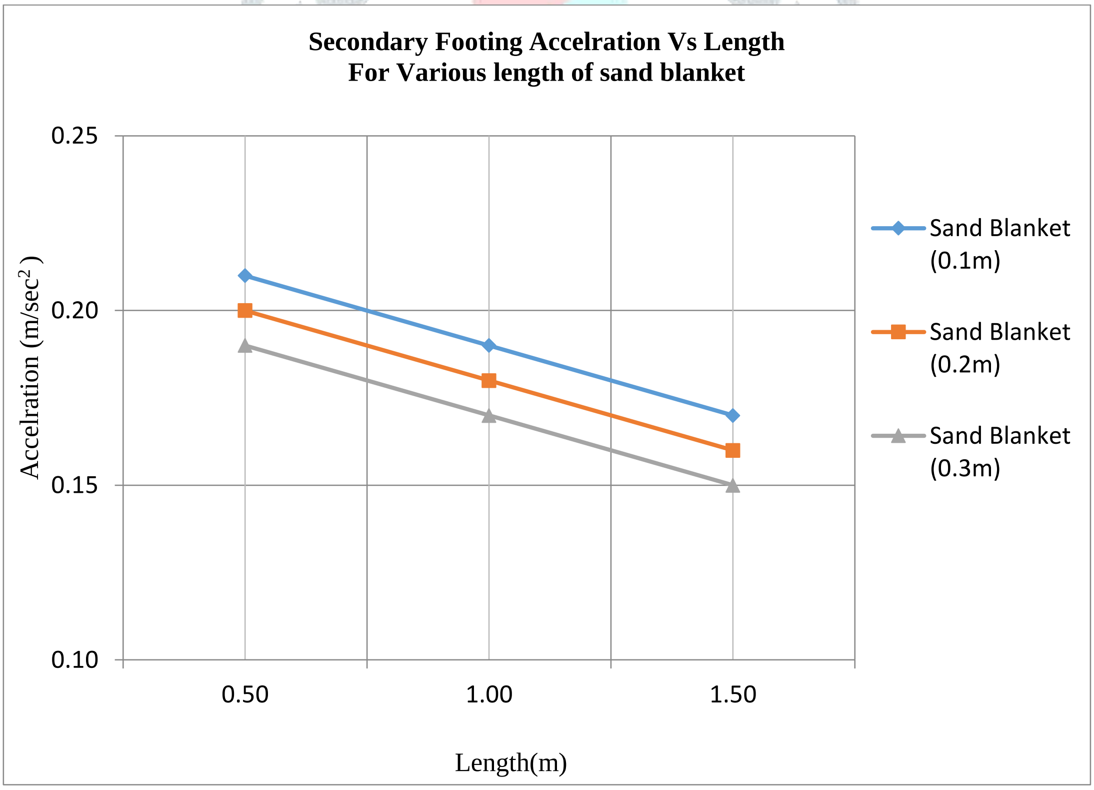
Geometrical Model for sand blanket between footings

Figure No. 9



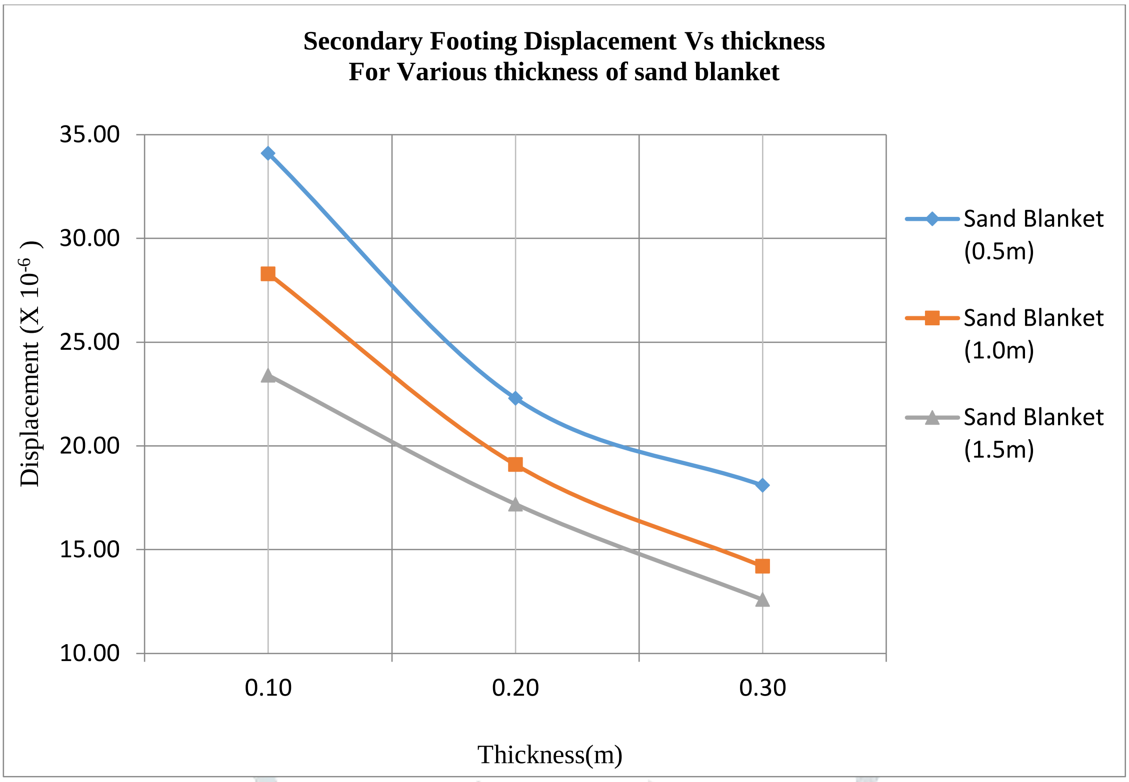
Displacement Vs Length for sand blanket of various length and fixed thickness

Figure No. 10



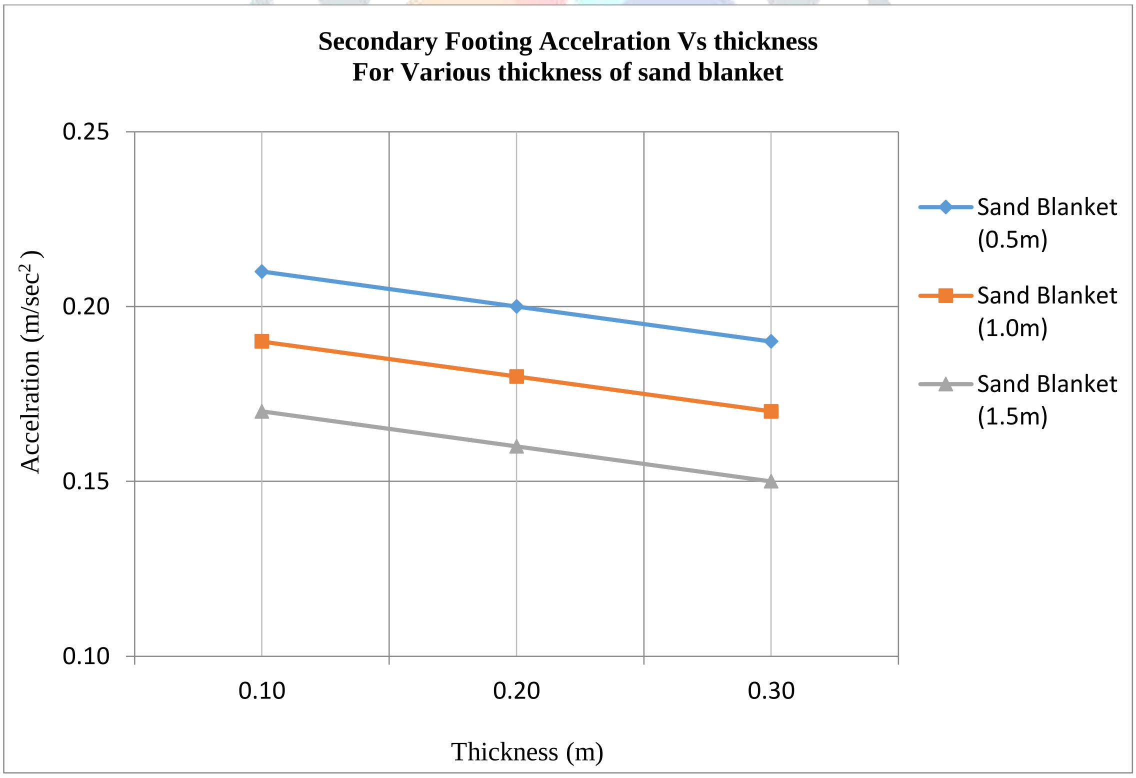
Acceleration Vs Length for sand blanket of various length and fixed thickness

Figure No. 11



Displacement Vs thickness sand blanket of various thickness and fixed length

Figure No. 12

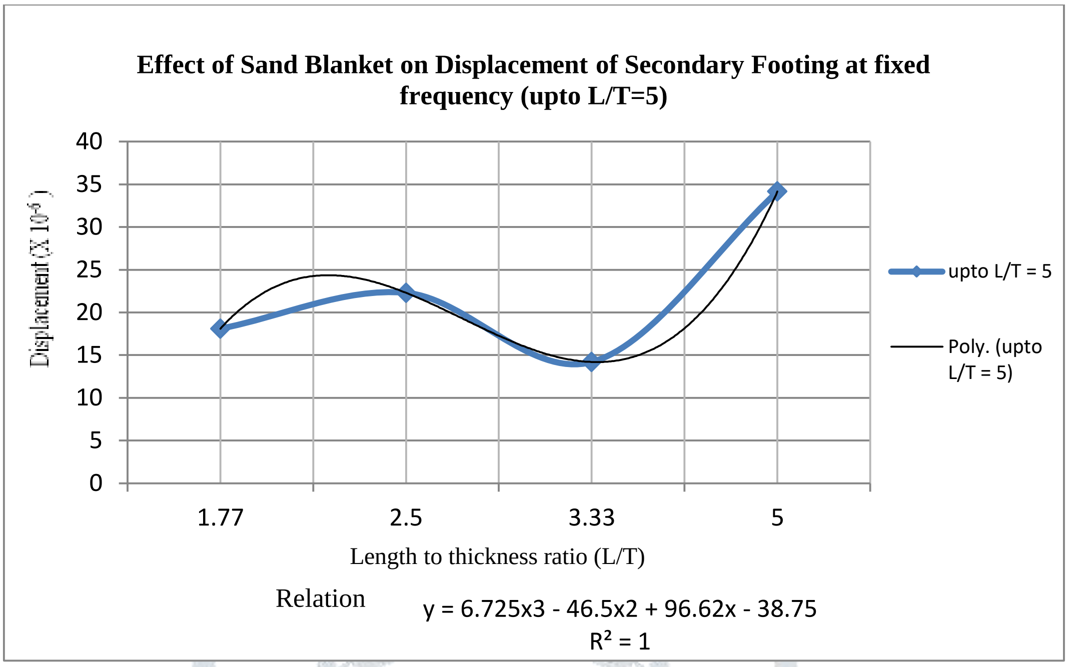


Acceleration Vs thickness sand blanket of various thickness and fixed length

Figure No. 13

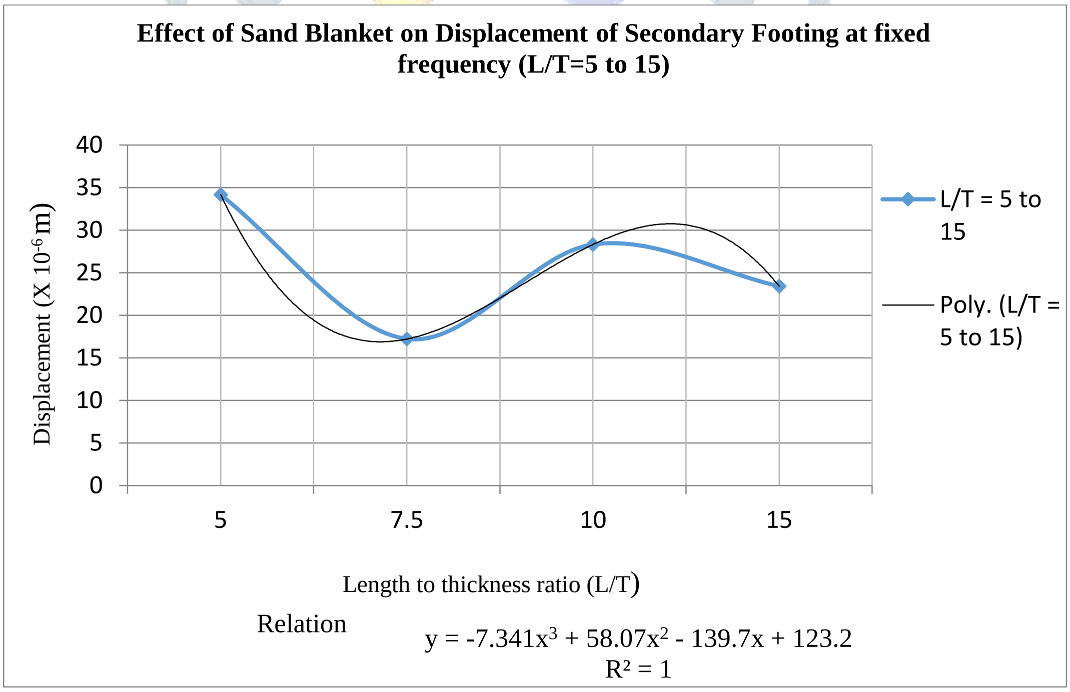
Effect of Sand Blanket on Displacement of Secondary Footing at fixed frequency

For this purpose the plot is made between L/T ratio & displacement to see the trend of sand blanket effect at particular frequency is studied and relation between displacement and L/T ratio for two cases is obtained as follows:-



Effect of Sand Blanket on Secondary Footing upto L/T=5

Figure No.14



Effect of Sand Blanket on Secondary Footing L/T=5 to 15

Figure No.15

6. Conclusion

i. While doing analytical work on PLAXIS results are compared with previous done experimental work. The result of primary footing has difference about average 5%.The result of secondary footing has difference about average 20%. Considering the difference of results within limits the assumption and methodology considered in the analytical approach are appropriate and satisfactory considering the difference between results within limits the assumption and methodology considered in the analytical approach are appropriate and satisfactory.

ii. The results under various combination of spacing's between footing shows increasing the spacing ratio form S/B 0.45 to 1.8 decreases displacement by 58% and ground accelerations by 60%.

iii. The results of different overburden pressure on secondary footing shows increasing the overburden pressure on secondary footing from 5kN/m^2 to 20 kN/m^2 decreases displacement by 50% and ground accelerations by 20%.

iv. Using sand blanket as damping medium in suitable combination like 0.3m thick and 1.5m long in present study peak displacement can be minimized to 65% and similarly accelerations can be minimized by 28%.

v. By increasing the thickness of blanket from 0.1m to 0.2 m dampens the displacements by 35%. Whereas increasing length from 0.5m to 1m dampens displacements by 17%. So the effect of increase in thickness of sand blanket is more beneficial and dominating then increasing length of the sand blanket.

7. Acknowledgement

The author is highly grateful to The Director, Guru Nanak Dev Engineering College (GNDEC), Ludhiana, for providing this opportunity to carry out the present thesis/work. The constant guidance and encouragement received from Dr. K.S.Gill, Prof. and Head of Department of Civil Engineering, GNDEC Ludhiana has been of great help in carrying out the present work. The help rendered by Prof. Prashant Grag, Assistant Professor, Civil Engineering Department, GNDEC, for the literature and showing path of research is greatly acknowledged. The author expresses gratitude to other faculty member of Civil Engineering Department, GNDEC for their intellectual support throughout the course of this work.

References

Gazetas, G. & Makris, N. (2010) "Dynamic pile-soil-pile interaction. Part 1: analysis of axial vibration" International journal of earthquake engineering VOL. 20, ISSN 115-132 (2010).

Hadi, K. (2016) "Dynamic Behavior of Machine Foundation on Two-Layer Soil System" international journal of engineering and development, Vol-19 ISNN 1813-7822.

Ishihara, K. & Ansal, A.M (2008) "Dynamic behavior of soil, soil amplification and soil-structure interaction." Journal of earthquake engineering ,Greece Vol-19(3),ISNN 355-381(2008)

IS 2974 (Part-I): 1987 Design and construction of machine foundation(First Revision)

IS 2974 (Part-III): 1992 Design and construction of machine foundation for rotary type of machine

Kumar, P. & Ghosh, P. (2009) "Interference Effect of Two Nearby Strip Footings on Reinforced Sand" Contemporary Engineering Sciences, Vol. 2, No. 12, ISNN 577 – 592(2009)

Nikam, S. & Bhagat, S.R. (2014) "Dynamic Behavior of Underground Structures during Earthquake: A Critical Review" International Journal of Engineering Research Volume No.5, Issue (Special 1) , ISSN:2319-6890

Ramesh, H.N & Kumar, H.A. (2005) "Effect of Static and Cyclic Loading on Behavior of Fiber Reinforced Sand" IOSR journal of engineering ISSN 2278-8719.

Romo, M.P. & Shelley, E.O (2012) " Modeling the dynamic behavior of Mexican clays" published in eleventh world Conference of earthquake engineering, Mexico Paper ID -1028 : ISBN 0080428223.

Srinivasulu, P. (2001) "Handbook of machine foundations" Book on design & construction of machine foundation by Tata McGraw Hill publishers, New Delhi

Swain, A. & Ghosh, P. (2016) "Experimental study on dynamic interference effect of two closely spaced machine foundations" Canadian geotechnical journal,Vol-53(2) ISNN: 0008-3674

Tafreshi, S.N & Mehrjardi, G.H. (2002) "Experimental and numerical investigation on circular footing subjected to incremental cyclic loads" International journal of civil engineering, Vol 4(2) ISNN 216-244(2002

Vivek, P. & Ghosh, P.(2008) "Dynamic interaction of two nearby machine foundations on homogenous soil" international geo congress journal ,roorkee Vol 1, No, 08, ISNN 457-477(2008)