J. Basic. Appl. Sci. Res., 6(3)20-27, 2016
© 2016, TextRoad Publication

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Study of Model Experiment of Embankment Reinforcement by Using Bus Wood (Memamelica Sp) at Soft Soil Deposition

Philipus Betaubun*, Hairulla, Anton Topan

Lecturer on University of Musamus, Merauke-Papua, Indonesia

Received: December 19, 2015
Accepted: February 1, 2016

ABSTRACT

Bus wood in Merauke residence much found in around nature. Bus wood also may be used as alternative material to reinforcement at soil which the support capability less well for construction and embankment. The nature of bus wood life in swamp which as soft soil territory may be used as reinforcement material by raft and pole model, it is an innovation in effort to reduce the soil deformation and degradation as *uniform settlement*. Along with the development the knowledge especially geotechnical field in this case soil reinforcement method has developed with rapid at the last decade either to using conventional material or other material usage. To investigate the effectiveness of raft and pole model of bus wood which able to reducing the soil degradation is used variation model of long pole used. It is expected that result of reinforcement testing model by using the wood bus at laboratory model typical testing able to reducing vertical deformation and support to retaining *vertical* load result of load given during the testing. Characteristic of soil and bus wood in testing use SNI and ASTM standard. This testing use an *Experimental method*, testing development is done at laboratory by examining the enforcement laboratory model design at test cases with 240x122x60 cm measurement. Is designed a road embankment model at soft soil by varying the deep of wood bus funnel at 10 cm, 20 cm, 30 cm, and 40 cm deepness which supported the deposit of road body and is tested by the loading plate as load flatted. To investigate the effectiveness of wood bus funnel may reduce the soil degradation. Result of the testing at laboratory scale model show that the enforcement which use bus wood funnel is greatly effective to support the embankment existed on base soil. During the testing the loading, base soil only experience deformation mainly small. While, bus wood funnel may give the significantly enough support to retain the vertical load caused by load given during testing.

KEYWORDS: bus wood, soft soil, soil reinforcement

INTRODUCTION

The number of construction of road embankment on soil which less have the support capability (soft soil), caused the happening the degradation hugely and lateral movement. Various methods were developed to overcome the happened problems caused by road construction on soft soil. In each construction is needed foundation as strong and sturdy construction base. It is caused, foundation as construction base have to able to bear the whole construction load and the other one, to is continued up to soil layer at certainty deepness. Civil technique construction generally includes mainly two parts, that is, below structure and up structure. In this case, below, structure as foundation interacted with soil produces the support capability which able to bear and give security at structure on up. Breakage on construction is not only caused by construction structure, but also the soil circumstance whereby construction structure is located. Cause of the breakage as mentioned is the bigness of the happened degradation and the lower of the support capability of soil, like at cohesive soil, it is especially containing water rate high enough. Therefore, need to consider thoroughly about the support capability of those the cohesive soil, whether be needed the existing the repairing effort or soil stabilization to get soil nature wished until construction breakage able to be prevent, [1].

Method to giving soil enforcement as the method is developing at present, mainly to using materials sourced from nature. Bus wood is one of kind of plant which much fertile grows at Merauke Residence until easy to meet and the price relatively cheap. Bus wood has a good feature for construction usage, because bus wood is strong, straight, light, and easy to do. Bus wood in spherical form is usually worn to construction like home, warehouse, bridge, ladder, even in scaffolding. Various methods to repair soil may be used, however, in using the precise methods have to consider various aspects, among other is site location will be executed the job, impact to the environment that will be caused, and other factors must to be considered is the economic value also the easiness in the performing. *Effectiveness of raft and pole foundation to reduce the soil degradation with the numerical method by Prof. Dr. Ir. Lawalenna Samang, MS., M.Eng., Dr.Eng. Tri Harianto, ST., MT. and Ir. Achmad Zubair, MT.* Raft and pole foundation design was introduced at this study to reduce the soil degradation. Element Method until is used to investigate the effectiveness of raft and pole foundation to reduce the soil degradation specially at roadway built in swamp territory, [2][3]. Furthermore, numerical model is used to learn the influence of type and the deepness of foundation installed at the square. Soil degradation and deformation is analyzed in this research to

***Corresponding Author:** Phillipus Betaubun, Lecturer on University of Musamus, Merauke-Papua, INDONESIA. Email: mrphilbet@gmail.com

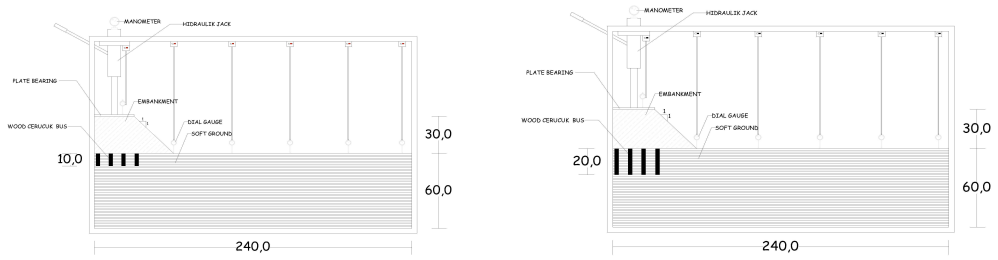
determine the effectiveness and the possibility of application of this foundation model at the square. Result of element method until used, show that raft and pole foundation type significantly down the bigness of degradation from road body result of surface load. Deformation happened at road body without enforcement up to 0.553 m, while with enforcement 3 m and 5 m in each 0.246 m and 0.225 m.

Full scale testing and bamboo mattress funnel enforcement analysis to road body deposit on soft soil in location of Tambak Oso, Surabaya by Prof. Ir. Masyhur Irsyam, MSE, Ph.D and Ir. Sugeng Krisnanto, MT. from analysis result and field observation done, could be taken a conclusion from result of observation of trial embankment is known that by using bamboo mattress funnel system the support capability of base soil enough to bear the load result of trial embankment, deposit has an enough slope stability, while, the degradation happened, relatively uniform. After observation is done over 3 month, run of the degradation of base soil have been occurred at the end of observation is estimated have reached 30%. [4] *Study of usage of pole foundation manufacture from bamboo as soil reinforcement at deposit construction on soft soil by Ir. Helmy Darjanto MT, Ir. Djoko Soepriyono MT, SH, M.Hum, and Dr. Ir. Akhmad Basuki Widodo MSc.* This research use *Petung Bamboo* as soil reinforcement at deposit construction. Stability of deposit slope and base soil become one of planning in this research. Numerical analysis use plaxis program (1998) that the output result, that is, deformation/total displacement and safety number between soil without bamboo enforcement and that to be given by pole bamboo enforcement is compared. [5][6]. Outcome of this research shows that the pole bamboo as soil reinforcement has a higher safety number, therefore, able to overcome the embankment up to achieve 20 – 30%.

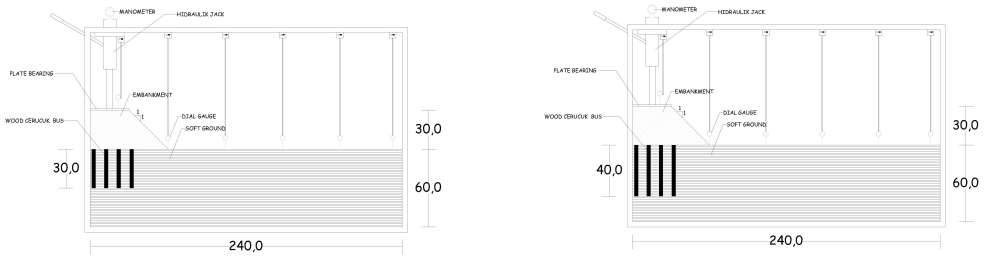
MATERIALS AND METHODS

In this research is begun by collecting soft soil characteristic data which has a support capability extremely low, that is, include testing a physical feature consisted of water rate, soil specific weight, soil grain analysis, soil volume weight, and also soil mechanical feature, that is, standard density, soil used in this research derived from origin soil located at Rimba Jaya Village, Merauke District, Merauke Residence. In physical feature and soil mechanical testing is used SNI and ASTM standard [7], according to the kind of testing conducted. Furthermore, to be done a characteristic testing of physical feature and white bus wood mechanical. Examination of physical feature and bus wood mechanical feature at this research is based on ISO 22157-1(2004) and ISO 22157-2 (2004). The examination of the physical feature which to be done is examination against water rate of bus wood. While, examination mechanical characteristic of bus wood include pull power, pressure power, sliding power, refraction power, elastic modulus [8], the used bus wood is white bus wood species (*Eucalyptus sp*) originated of District Sermayam, Tanah Miring, Merauke residence. In applying the laboratory model testing [9][10] is done at 4 testing model by variation bus wood funnel deepness, seen at Picture 1. Testing of bus wood funnel enforcement is as follow: (a) variation of 10 cm deepness, (b) variation of 20 cm deepness, (c) variation of 30 cm deepness, and (d) variation of 40 cm deepness.

Preparing, observation and taking of data on clay soil model with bus wood raft and bus wood pole enforcement, [11]. Clay soil is included into testing cases measured at 50 cm x 60 cm x 240 cm. base soil use a density degree is 50% of maximum density founded at density testing in compact standard. In this testing base soil is fashioned as high as 60 cm. bus wood rafts consisted of one cross section direction layer. The used dimension is 40 cm width and 50 cm long, [12]. The used bus wood pole is positioned from the end of the bus wood raft with the distance among the pole is 20 cm. after the testing cases is filled by soil, bus wood raft then is located and bus wood poles entered into soil and bunched become one unity with bus wood raft as the enforcement model. Clay soil once again entered to covering the surface of the bus wood raft to facilitate of giving the load. Deposit soil as clay soil, then is entered on bus wood raft enforcement, fashioned as road embankment as high as 30 cm. bearing plate is located at the surface and the latter will be loaded using a hydraulic jack means. Dial indicator (*dial gauge*) located at the position. The first precisely on bearing plate to read the degradation; the second is located at the edge of inclination of embankment to read the deformation occurred at the edge of embankment; the other dial is located of the edge of embankment to read the deformation occurred at the surface of soil. [13][14][15].



(a) (b)



(c) (d)

Figure 1. The bus wood funnel enforcement model testing (a) variation in the 10 cm deepness, (b) variation in the 20 cm deepness, (c) variation in the 30 cm deepness, and (d) variation in the 40 cm deepness.

RESULTS AND DISCUSSION

Result of testing at physical feature and soft soil mechanical

From testing result in laboratory was founded physical characteristic and soil mechanical soil data could be seen at the table 1. Table 1. Recapitulation of inspection result of origin soil characteristic

Table 1. Recapitulation of inspection result of origin soil characteristic

Kind of Test		Result of Test	
Testing of characteristic of original soil			
Water content (w)		43.40	%
Specific gravity (Gs)		2.70	
Sieve Analysis test			
a.	Soft granular	57.50	%
b.	Hard granular	42.50	%
Atterberg			
a.	Liquid limit (LL)	45.97	%
b.	Plastic limit (PL)	31.54	%
c.	Plastic Index (PI)	14.42	%
d.	Shrinkage limit (SL)	16.47	%
Unit Weight		1.66	gram/cm³
Compasy of Standard			
a.	Maximum Dry Density, gd (MDD)	1.33	gram/cm³
b.	Optimum Moisture Content (OMC)	36.00	%
Mechanic characteristic test of sub grade			
Unit Weight of Soil Compaction		1.44	gram/cm³
Free Stress Power			
a.	Qu	0.22	Kgf/Cm²
b.	Modulus of Elasticity	2000.00	kN/m²
Direct Shear Test			
a.	Cohesion (c)	0.06	0.00
b.	Internal Friction Angle (Ø)	11.31	°
Mechanic characteristic test of Embankment Soil			
Unit Weight of Soil Compaction		1.66	gram/cm³
Free Stress Power			
a.	Qu	2.25	Kgf/Cm²
b.	Modulus of Elasticity	5555.56	kN/m²
Direct shear test			
a.	Cohesion (c)	0.19	0.00
b.	Internal Friction Angle	11.13	°

Source: result of data processing

Characteristic feature and *bus wood* mechanical

From testing result in laboratory was founded characteristic and bus wood mechanical soil data could be seen at the table 2. Table 2. Recapitulation of inspection result of characteristic and bus wood mechanical

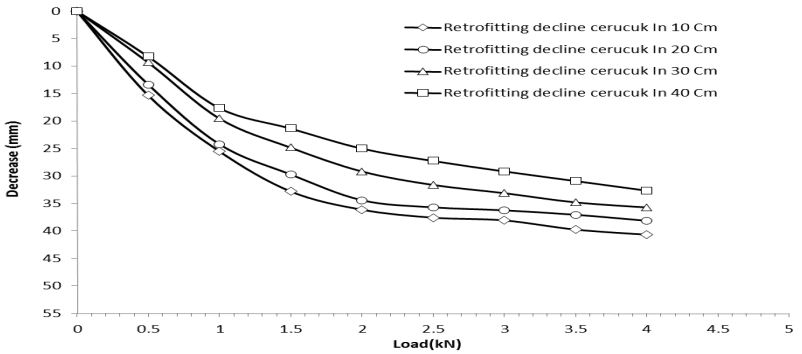
Table 2. Recapitulation of inspection result of characteristic and bus wood mechanical

No	Kind of test	Result of test	
1	Water content test of wood	21.58	%
2	Pressure draw of wood	18.51	Mpa
3	Pressure strength of parallel fibre wood	23.76	Mpa
4	Pressure strength of perpendicular fibre wood	14.71	Mpa
5	Warping strength of wood	106.22	Mpa
6	Cracking strength of wood	29.91	Mpa
7	Bending strength test of wood	5.00	Mpa

Source: result of data processing

Testing result of soil laboratory model by using the bus wood funnel enforcement

Model testing result could be seen at figure 2 Figure 2. Graphic of testing result of laboratory model in load vs. degradation connection at this below:



Source: result of data processing

Figure 2. Graphic of testing result of laboratory model in load vs. degradation connection

Testing result of laboratory model at soft soil which uses bus wood funnel enforcement by 10 cm deepness, experience a bigger degradation, that is, 40.70 cm with ultimate load is 4 kN. At the second model testing by using the bus wood funnel at the 20 cm deepness, from this testing result the degradation happened could be deducted, that is, as big as 2.50 mm that is as big as 38.20 mm at ultimate loading as big as 4 kN. The third testing model by deepness of bus wood funnel as big as 30 cm able to reduce the degradation compared with bus wood funnel enforcement by 10 cm deepness as big as 5.00 mm and into 20 cm as big as 2.50 mm, by the degradation happened as big as 35.70 mm at ultimate loading as big as 4 kN. From the result of the testing could be interpreted that soft soil by enforcement at the moment is loaded in maximum before trial embankment experience collapse as big as 4 kN and experience the happened degradation as big as 13.57 % of embankment deposit model high with bus wood funnel enforcement at the 10 cm deepness, also samples with the enforcement 20 cm deepness at the same load experience the degradation as big as 112.73 % of embankment model high, for testing samples of bus wood enforcement with 30 cm deepness, at the same loading experience the degradation as big as 11.90 % and testing with bus wood enforcement by 40 cm deepness at the same loading as big as 10.88 %. [6][7].

Testing result pattern into *bus wood* funnel toward embankment degradation and base soil deformation

From the testing result which was done in laboratory show that result of testing of *bus wood* funnel enforcement by 10 cm, 20 cm, 30 cm, also 40 cm deepness, shown the embankment degradation testing result and base (heaving) soil deformation at 1 kN, 2 kN, and 3 kN and 4kN loading.

Table 3. Connection in deepness toward embankment downing and base soil deformation result of bus wood funnel 10 cm deepness.

No	Dist	Bus wood funnel enforcement with 10 cm deepness				Remark
		Load 1 kN	Load 2 kN	Load 3 kN	Load 4 kN	
1	0	-25.53	-36.15	-38.10	-40.70	Reduction dial
2	25	-25.53	-36.15	-38.10	-40.70	
3	50	0.90	1.4	3.0	5.7	Dial 1
4	98	0.80	1.2	2.1	3.8	Dial 2
5	145	0.40	0.6	1.0	1.5	Dial 3
6	193	0.30	0.5	0.8	1.1	Dial 4
7	240	0.15	0.3	0.3	0.5	Dial 5

Source: result of data processing

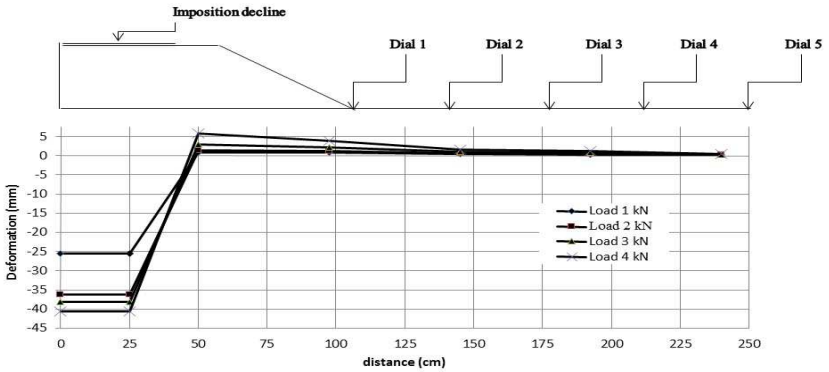


Figure 3. Graphic of distance connection model testing vs. base soil deformation with bus wood funnel enforcement 10 cm deepness

Figure 3. Graphic of distance connection model testing vs. base soil deformation with bus wood funnel enforcement 10 cm deepness, and Table 3. Connection in deepness toward embankment degradation and base soil deformation result of bus wood funnel 10 cm deepness, shown the result that the bigger of loading, the bigger the deformation happened at base soil. By working load as big as 1 kN, then deformation happened at 1 dial as big as 0.90 mm, 2 dial as big as .80 mm, 3 dial as big as 0.40 mm, 4 dial as big as 0.30 mm. 5 dial as big as 0.15 mm. at 2 kN loading, deformation happened at each dial placement is 1 dial as big as 1.40 mm, 2 dial as big as 1.20, 3 dial as big as 0.60 mm, 4 dial as big as 0.50 mm, 5 dial as big as 0.30 mm. furthermore, at 3 kN loading, deformation occurred is 1 dial as big as 3.00, 2 dial as big as 2.10 mm, 3 dial as big as 1.00 mm, 4 dial as big as 0.80 mm, 5 dial as big as 0.30 mm. also at 4 kN loading, reading of 1 dial as big as 5.70 mm, 2 dial as big as 3.80 mm, 3 dial as big as 1.50 mm, 4 dial as big as 1.10 mm, 5 dial as big as 0.50 mm.

Table 4. The deepness connection toward embankment degradation and result base soil deformation by bus wood funnel 20 cm deepness.

No	Dist	Bus wood funnel enforcement with 20 cm deepness				Remark
		Load 1 kN	Load 2 kN	Load 3 kN	Load 4 kN	
1	0	-24.25	-34.45	-36.30	-38.20	Reduction dial
2	25	-24.25	-34.45	-36.30	-38.20	
3	50	0.80	1.2	2.4	4.2	Dial 1
4	98	0.60	1.0	1.8	2.3	Dial 2
5	145	0.30	0.4	0.8	1.2	Dial 3
6	193	0.25	0.3	0.5	0.9	Dial 4
7	240	0.05	0.1	0.2	0.3	Dial 5

Source: result of data processing

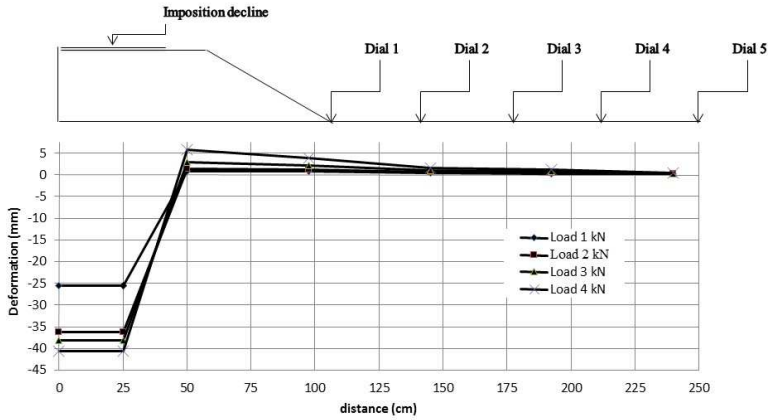


Figure 4. Graphic of testing result of distance connection model vs. base soil deformation with bus wood funnel enforcement 20 cm deepness

At the conducted enforcement testing as is shown at Figure 4 such as Graphic of testing result of distance connection model vs. base soil deformation with bus wood funnel enforcement 20 cm deepness and table 4. The deepness connection toward embankment degradation and base soil deformation by result of bus wood funnel

20 cm deepness, show a result that the bigger of loading, the bigger the deformation happened at base soil. With load that work as big as 1 kN, thus deformation happened at 1 dial as big as 0.80 mm, 2 dial as big as 0.60 mm, 3 dial as big as 0.30 mm, 4 dial as big as 0.25 mm, 5 dial as big as 0.05 mm. at 2 kN load, the deformation happened at each dial placement is 1 dial as big as 1.20 mm, 2 dial as big as 1.00 mm, 3 dial as big as 0.40 mm, 4 dial as big as 0.30 mm, 5 dial as big as 0.10 mm. furthermore at 3 kN load, the deformation happened 1 dial as big as 240 mm, 2 dial as big as 1.80 mm, 3 dial as big as 0.80 mm, 4 dial as big as 0.50 mm, 5 dial as big as 0.20 mm, and at 4 kN maximum load, the deformation as big as 1 dial as big as 4.20 mm, 2 dial as big as 2.30 mm, 3 dial as big as 1.20 mm, 4 dial as big as 0.90, 5 dial as big as 0.30 mm.

Table 5. The deepness connection toward embankment degradation and base soil deformation by result of bus wood funnel 30 cm deepness.

No	Dist	Bus wood funnel enforcement with 30 cm deepness				Remark
		Load 1 kN	Load 2 kN	Load 3 kN	Load 4 kN	
1	0	-19.53	-29.15	-33.10	-35.70	Reduction dial
2	25	-19.53	-29.15	-33.10	-35.70	
3	50	0.10	0.30	1.00	2.20	Dial 1
4	98	0.05	0.20	0.50	1.10	Dial 2
5	145	0.00	0.10	0.30	0.80	Dial 3
6	193	0.00	0.05	0.15	0.30	Dial 4
7	240	0.00	0.00	0.00	0.00	Dial 5

Source: result of data processing

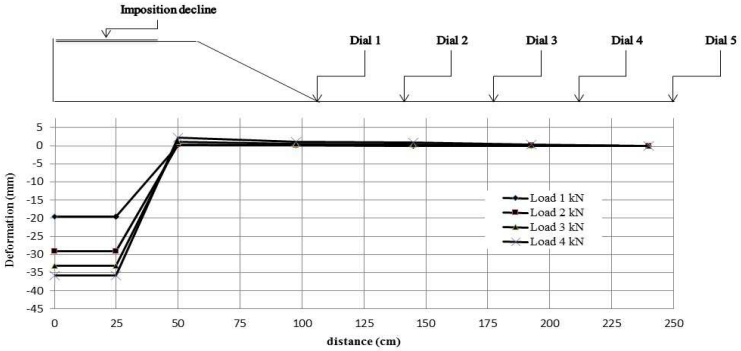


Figure 5. Graphic of testing result of distance connection model vs. base soil deformation with bus wood funnel enforcement 30 cm deepness

From the testing result as is shown at the Figure 5 such as Graphic of testing result of distance connection model vs. base soil deformation with bus wood funnel enforcement 30 cm deepness, and Table 5 The deepness connection toward embankment degradation and base soil deformation by result of bus wood funnel 30 cm deepness. Show the result that bigger and bigger of deformation at base soil along with the increasing of load bigger and bigger, [18]. By load which work as big as 1 kN, then the happened deformation at 1 dial as big as 0.10 mm, 2 dial as big as 0.05 mm, 3 dial as big as 0 mm, 4 dial as big as 0 mm, 5 dial as big as 0 mm. at 2 kN load, the deformation happened at each dial placement is 1 dial as big as 0.30 mm, 2 dial as big as 0.20 mm, 3 dial as big as 0.10 mm, 4 dial as big as 0.05 mm, 5 dial as big as 0 mm. furthermore, at 3 kN load, the deformation happened at 1 dial as big as 1.00 mm, 2 dial as big as 0.50 mm, 3 dial as big as 0.30 mm, 4 dial as big as 0.15 mm, 5 dial as big as 0 mm, and at 4 kN maximum load, the deformation as big as 1 dial as big as 2.20 mm, 2 dial as big as 1.10 mm, 3 dial as big as 0.80 mm, 4 dial as big as 0.30 mm, 5 dial as big as 0 mm.

Table 6 The deepness connection toward embankment degradation and base soil deformation by result of bus wood funnel 40 cm deepness.

No	Dist	Bus wood funnel enforcement with 40 cm deepness				Remark
		Load 1 kN	**Load 2 kN**	**Load 3 kN**	**Load 4 kN**	
1	0	-17.64	-25.00	-29.15	-32.65	Reduction dial
2	25	-17.64	-25.00	-29.15	-32.65	
3	50	0.10	0.30	0.70	1.00	Dial 1
4	98	0.00	0.15	0.30	0.80	Dial 2
5	145	0.00	0.00	0.20	0.65	Dial 3
6	193	0.00	0.00	0.00	0.00	Dial 4
7	240	0.00	0.00	0.00	0.00	Dial 5

Source: result of data processing

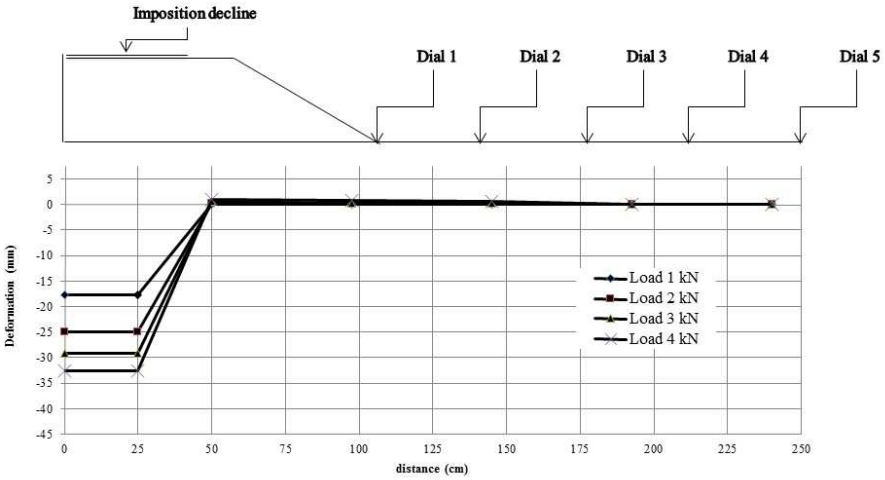


Figure 6 Graphic of testing result of distance connection model vs. base soil deformation with bus wood funnel enforcement 40 cm deepness.

From Figure 6 Such as Graphic of testing result of distance connection model vs. base soil deformation with bus wood funnel enforcement 40 cm deepness and Table 6. The deepness connection toward embankment degradation and base soil deformation by result of bus wood funnel 40 cm deepness; show that the bigger the load, the bigger the deformation happened at base soil. With load that work as big as 1 kN, then the deformation happened at 1 dial as big as 0.10 mm, 2 dial as big as 0 mm, 3 dial as big as 0 mm, 4 dial as big as 0 mm, 5 dial as big as 0 mm. at 2 kN load, the deformation happened at each dial placement is 1 dial as big as 0.30 mm, 2 dial as big as 0.15 mm, 3 dial as big as 0 mm, 4 dial as big as 0 mm, 5 dial as big as 0 mm. Next, at 3 kN load, the deformation happened at 1 dial as big as 0.70 mm, 2 dial as big as 0.30 mm, 3 dial as big as 0.20 mm, 4 dial as big as 0 mm, 5 dial as big as 0 mm, also at 4 kN load, the deformation as big as 1 dial as big as 1.00 mm, 2 dial as big as 0.80 mm, 3 dial as big as 0.65 mm, 4 dial as big as 0 mm, 5 dial as big as 0 mm.

CONCLUSION

By using bus wood funnel enforcement at testing done, then is founded a happened embankment degradation pattern may be reduced it degradation. The effectiveness of bus wood funnels enforcement usage as base soil enforcement it is good to use, which more in the used enforcement to support the embankment, the bigger the degradation could be reduced and the happened deformation smaller and smaller.

ACKNOWLEDGEMENT

Researchers feel proud because able to finish this research over field study and laboratory testing. We are researchers accomplish gratitude to the whole civitas academician especially Technical Faculty of University of Musamus Merauke. To the whole parties who have assisted to complete this research, we render thanks.

REFFERENCES

1. Das, Braja M. (1995), alih bahasa Muchtar dan Nur Endah (2002): *Mekanika Tanah* (Prinsip-prinsip Rekayasa Geoteknis) Jilid I, Erlangga, Jakarta.

2. Samang, L., Harianto, T., dan Zubair, A. (2010), Efektifitas Pondasi Raft dan Pile Dalam Mereduksi Penurunan Tanah Dengan Metode Numerik. *Konfrensi Nasional Teknik Sipil 4 (KoNTeks*), Sanur-Bali, 2-3 Juni.

3. Bowles, J.E. (1983), *Engineering Properties of Soils and Their Measurement*, Mc.*Grawhill Book Company* , Singapore.

4. Bowles, J.E. (1993), Alih Bahasa Ir.Johan Kelana Putra Edisi Kedua, *Sifat-Sifat Fisis Dan Geoteknis Tanah*, Penerbit Erlangga, Jakarta.

5. Bowles, J.E. (1979), *Fondation Analysis and Engineering*, Second edition, Publishing McGraw-Hill, New York

6. Indrasurya, B. M. (2000), *Teknologi Perbaikan Tanah Dan Alternatif Perencanaan Pada Tanah Bermasalah (Problematic Soils)*. Jurusan Teknik Sipil Fakultas Teknik Sipil Dan Perencanaan, Institut Teknologi Sepuluh Nopember.

7. ASTM, (1992), *ASTM Stabilisation With Admixture, American Society For Testing And Materials*, *Second Edition*.

8. Hamed N., Khairul A. K. dan Chong S. Y. (2011), Soil Improvement By Reinforced Stone Columns Based Onexperiments Work. *Electronic Journal of Environmental, Agricultural and Food Chemistry* Volum 2 10 (7), hal 2460-2478.

9. Budi, G. S. (2011), *Pengujian Tanah di Laboratorium*, Penerbit Graha Ilmu, Surabaya.

10. Hardiyatmo, C. H. (2010), *Mekanika Tanah 1*, Gadjah Mada University Press, Jakarta.

11. Wesley, L. D. (1977), *Mekanika Tanah*, Badan Penerbit Percetakan Umum, Jakarta.

12. Terzaghi, K (1987) *Soil Mechanics in Engineering Practice*, 2nd ed, Wiley, New York

13. A. Zahmatkesh & A. J. Choobbasti, (2010) Settlement evaluation of soft clay reinforced by stone columns, considering the effect of soil compaction. *Journal IJRRAS* Volum 3 (2), hal 159-166.

14. Craig, R.F. (1991), *Mekanika Tanah*. Diterjemahkan oleh Budi Susilo. Penerbit Erlangga, Jakarta.

15. F. Rackwitz dan M. Schubler, (2010) *Model Test On Granular Soil Columns For Ground Improvement Of Very Soft Soil*. Journal Department of Civil Engineering, Babol University of Technology, Babol, Iran Volum 1 (8), hal 1351-1356

16. Tandel Y.K, Solanki C.H dan Desai A.K, (2012) Reinforced granular column for deep soil stabilization *International Journal Of Civil And Structural Engineering* Volume 2, No 3, hal 720-730

17. Teodoru, I.B dan Toma, I.O. (2009), *Numerical Analysis of Plate Loading Test*. Publicat de Universitatea Tehnica, Gheorghe Asachi din Iasi, Tomul LV (LIX), Fasc. 1, 2009, Sectia CONSTRUCTII ARHITECTURA.

18. Poulos, H.G., E.H. Davis (1980), *Pile Foundation Analisis And Design,* Jhon Wiley and Sons Australia