Concentric Arches Model Validation with Embankment on soft soil using Pile with Geosynthetic Reinforcement for Indian Condition

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Abstract **:** Embankment on soft soil has always being an challenge to geotechnical engineers which has lead to different design codes and FEM analysis methods leading to application of an Geosynthetic piled reinforcement system. The number of design codes like BS 8006, CUR 226, ASIRI and EBGEO (2010) calculates the load transfer mechanism on embankments on soft soil with Geosynthetic Piled Reinforcement System by using different arching models proposed by Jones, Hewlett and Randolph and Zaeske which leads to calculation of load on geosynthetics to a higher side leading to uneconomical design. Number of Researchers have tried to analysis the load transfer mechanism by available FEM softwares like Plaxis,Abaqus etc due to design limitations of the available design codes. The Concentric Arches model as experimentally proven by Van Ekelen predicts realistic load values on geosynthetics leading to an economical design,leading to its inclusion in revision of CUR 226 (2015).The Concentric model has been numerically validated by Van preet using FEM software of Plaxis 2D and Plaxis 3D.This paper is an attempt to validate the concentric arches model proposed in Indian condition by using soil properties of coastal soft soil by considering suitable constitutive model available in the FEM software (plaxis 2D).

Keywords : BS 8006,CUR 226,EBGEO(2010),Plaxis,FEM

1. INTRODUCTION

Construction on weak soils has always been an challenge to Geotechnical Engineers.Various factors have to be considered during embankment designing on soft soils such as bearing capacity, differential settlement etc. To address this issue number of techniques like preloading, use of stone columns soil replacement are being used. The technique of Geosynthetic piled reinforcement which will be dealt here is also one used to counter above problems. Many design codes are available which are used to design the GRPS like BS 8006, CUR 226, EBGEO and ASIRI. In india IRC 113 is used for embankments on soft soils which is roughly based on BS 8006.The details of each design methods and the load transfer mechanism considered in the design codes are briefly explained below.

1.1 LOAD TRANSFER MECHANISM

The embankment load is transferred to the pile, geosynthetic reinforcement and subsoil in the manner as shown in figure 1. The load transfer mechanism is used to design the GR strip. Multiplying this GR strain by the GR stiffness gives the tensile force, which needs to be smaller than the long term GR tensile strength. The GR strain is calculated in two steps. Calculation step 1 divides the load – the weight of the embankment fill, road construction and traffic load – into two load parts. One part (load part A) is transferred to the piles directly. This part is relatively large because a load tends to be transferred to the stiffer parts of a construction. This mechanism is known as ‘arching’. The second, residual load part (B+C) rests on the GR (B) and the underlying subsoil (C). Calculation step 2 determines the GR strain on the basis of the result of step 1. Only the GR strips between each pair of adjacent piles are considered: they are loaded by B+C and may or may not be supported by the subsoil. The GR strain can be calculated if the distribution of load part B+C on the GR strip, the amount of subsoil support and the GR stiffness are known. An implicit result of this calculation step is the further division of load part B+C into parts B and C.

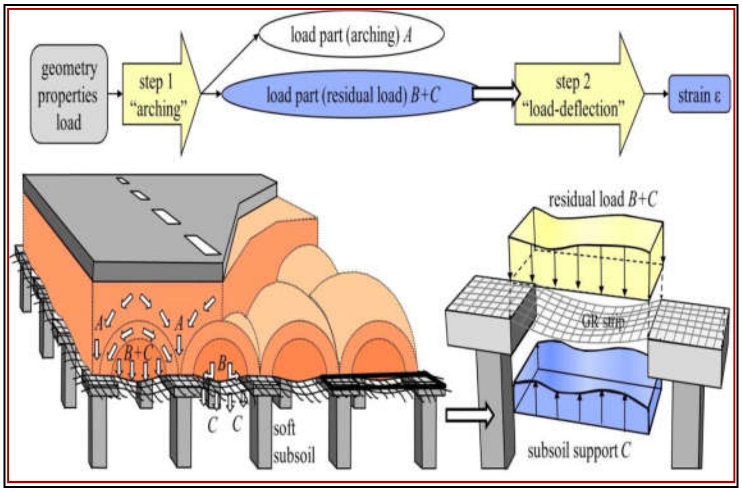

Figure Number 1. Load transfer in Geosynthetic reinforced piled supported embankments [Source: (7)]

1.2 DIFFERENT DESIGN CODES AVAILABLE

A) BS 8006:

British Standard BS8006 calculates the tensile force in the GR caused by the vertical load in the following four steps:

1. The vertical load is divided into three parts

2. The load on the reinforcement is concentrated on the strips of reinforcement between adjacent pile caps.

3. Full arching is assumed

4. The tensile force in the GR is calculated, from the vertical load part B.

B) EBGEO (2010) & CUR 226 (2010)-

Both the above design methods uses the Zaeske's Model and considering subsoil support combing the two together called EBGEO. It uses two step calculation as step 1 of arching and step 2 the load deflection behavior of GR or the 'membrane step'. EBGEO uses triangular Pressure distribution on GR as shown in Figure 2 below.

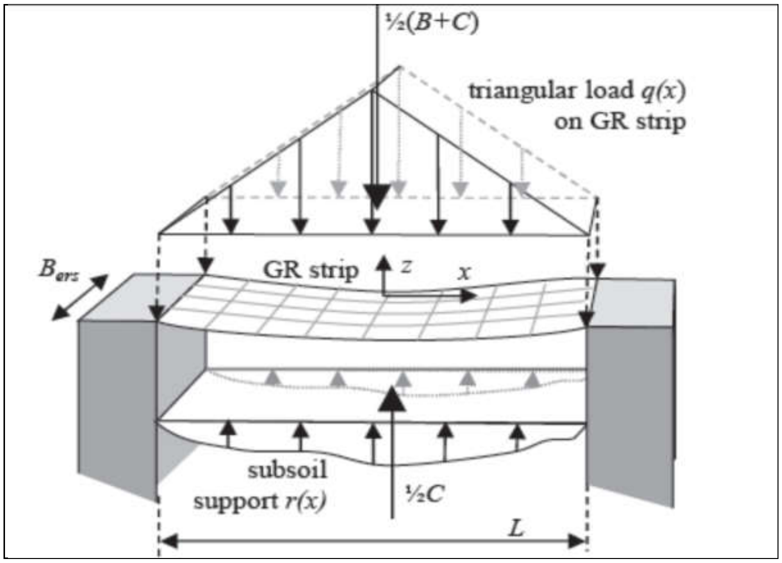

Figure 2. Calculation step 2 (membrane) of EBGEO; the GR strip is loaded by a triangular load q(x) and supported by the subsoil r(x)below the GR strip. [source: (7)]

1.3 Different Models

Two limit-state equilibrium models are frequently used in piled embankment design today. One of them is the Hewlett and Randolph model (1988) which was adopted in the French ASIRI guideline (2012) and suggested in BS8006 (2010) as an alternative for the original empirical model in BS8006. The other frequently used equilibrium model is Zaeske's model (2001, and also described in Kempfert et al., 2004),. Both the models are explained in figure 3a and 3b respectively. This model was adopted in the German EBGEO (2010) and the Dutch CUR226 (2010, described in Van Eekelen et al., 2010b), and will be referred to it here as 'EBGEO'.

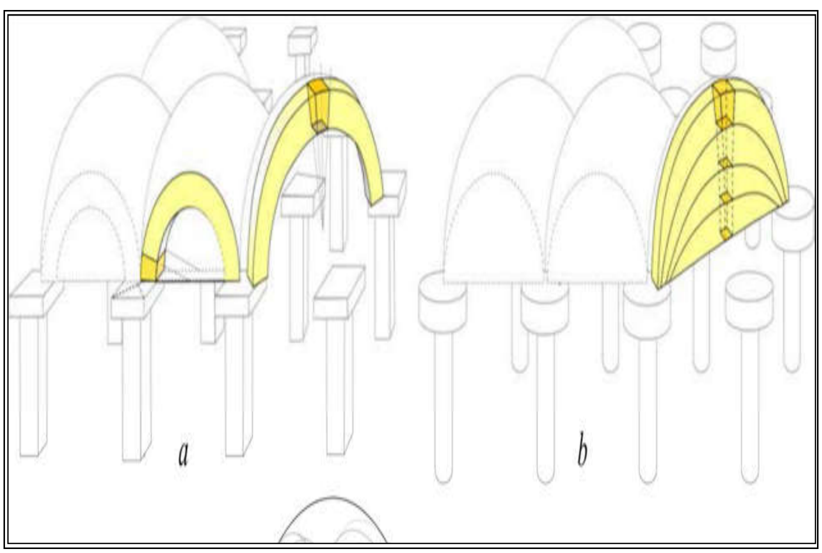

Figure Number 3a. Hewlett and Randolph (1988) consider the 'crown' element of the diagonal arch and the 'foot' element (just above the pile cap).Figure Number 3b. Zaeske (2001) considers the equilibruim of crown elements of diagonal arches [source: (8)]

1.4 Concentric Arches Method and Comparison with available models.

With equilibrium models, the pressure on the GR is calculated by considering the equilibrium of the arch. The models of Hewlett and Randolph (1988) and Zaeske (2001), are in widespread use.

These two models give quite satisfactory results when used in a design (the predicted loading on the GR is reasonable and on the safe side), but (1) do not explain the concentration of load on the GR strip, (2) do not explain or derive an inverse triangular load distribution on the GR strips and (3) do not give increasing arching during subsoil consolidation. Furthermore, the Hewlett and Randolph model is not meant for arching with GR, and not particularly suitable for partial arching situations, which are situations where the fill or embankment is thinner than the full arch height, in other words when $H < sd/2$. The Zaeske model can work with these low embankments.

Figure 4 introduces a 2D picture of the new model that describes the development of arching during subsoil consolidation, accompanied by an increasing GR deflection. In Figure 4 a, a small GR deflection results in the start of arch formation at the edge of the pile cap. At this location (the edge of the pile cap), the differential settlement between GR and pile cap is at a maximum and the load starts to be attracted to the stiffer pile cap, resulting in an increasing pile load A. Subsequently, increasing GR deflection closes the arch (b). Now, the piece of GR close to the pile behaves in a relatively stiff way because it is ‘attached’ to the pile and can move less freely than the GR in the middle. Another arch therefore starts to develop inside the first one (c). After this, more arches develop, each one smaller than the preceding one (d). Each smaller arch exerts a smaller force on its subsurface than the preceding larger arch. The arches give the directions of the main principal stresses: the major principal stress in the tangential direction and the minor principal stress in the radial direction. The creation of new arches is accompanied by increasing load transfer in the direction of the piles and a reduction of the load on the GR area between the piles. This results in a more or less inverse triangular load distribution on the GR strips. The process of arch development terminates in a set of concentric hemispheres which Figure 3.4.2 shows in 3D. The GR is essential in this model because, without GR, there will be a more or less even settlement of the area between the piles and the Concentric Arches cannot develop, as shown with 2D experiments by for example Hong et al. (2007) and Jenck et al. (2009).

The development of arching in a basal reinforced piled embankment has never been observed through, for example, a glass wall. However, the formation of subsequent new Concentric Arches as a result of settlement underground has been observed in experiments at the University of Cambridge . In these experiments, sand was poured onto a rubber tunnel. The largest differential settlements started, in this case, in the centre of the tunnel. In that case, a small arch in the fill occurred first, followed by a succession of larger arches.

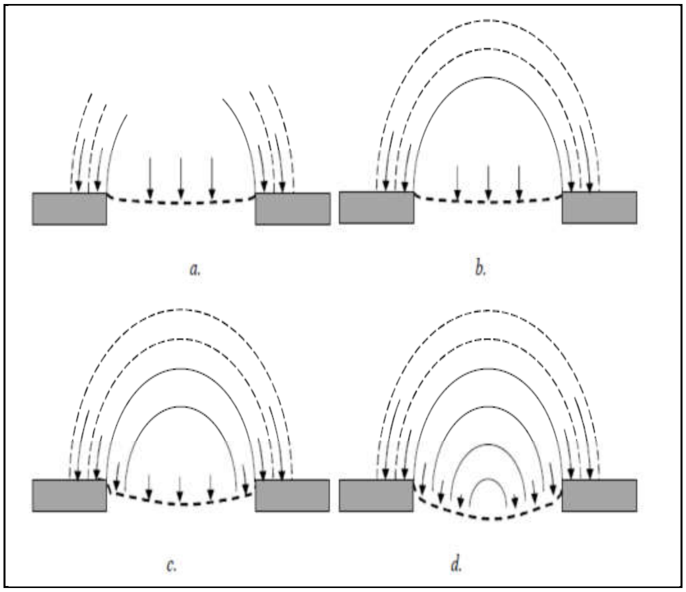

Figure Number 4. Increasing GR defection results in an increasing lateral transport of load via concentric arch-shaped stress paths and an inverse triangular load distribution on the GR. [source: (3)]

2. METHODOLOGY

Plaxis 2d is used for validation of the concentric arches due to unavailability of plaxis 3D version and also modeling and calculation time requirement along with the modeling precision and input parameter requirement is complex in 3D. An approach to validate the model in Abaqus was initiated but due to unavailability of soil models plaxis 2D is used.

- Procedure followed in plaxis 2d

A) Selection of Material properties

Mohr coloumb model for modeling of soil will be used. It gives a first order approximation of soil failure and is fairly accurate. The reason for apoting for this model is that the hardening soil model which is being used for soft clay soil to validate concentric arches model requires Eode,Eur and E50 values of the soil and those can be obtained after conducting of cyclic Triaxial test as their results are not available.

The material properties are as follows-

Table Number 1. Properties of Material

	Beams	**Subsoil**	**Fill**	**Interface Extens.**	**Interface GR-beam**	**Unit**
Type of Model	(LE)	(MC)	(MC)	(MC)	(MC)	
γdry	15	18	17	17	18	kN/m^3

γwet	-	20	19	19	20	kN/m 3
E	2.5x10^7	1.2x10^4	1.192x10^4	1.192x10^4	2.5x10^7	kN/m 2
ν	0	0.35	0.2	0.2	0	-
c	-	20	1.2	1.2	1	kN/m 2
φ	-	0	35	35	10	degree
ψ	-	0	0	0	1	degree
Rint	1	0.6	0.8	1	1	-

B) Modelled properties

The model describes a basic, simplified 2D (plane strain) situation. Two beams are modelled, using the following geometric parameters:

- Beam width b = 0.75 m
- Centre-to-centre distance sx = 2.25 m
- Embankment height H = 2.00 m
- Subsoil height Hsub = 1.0 m
- Top load p = 5.0 kN/m2

No pile/beam caps are used in this geometry. All boundary conditions are standard conditions (bottom fixed in all directions, sides fixed in lateral direction).

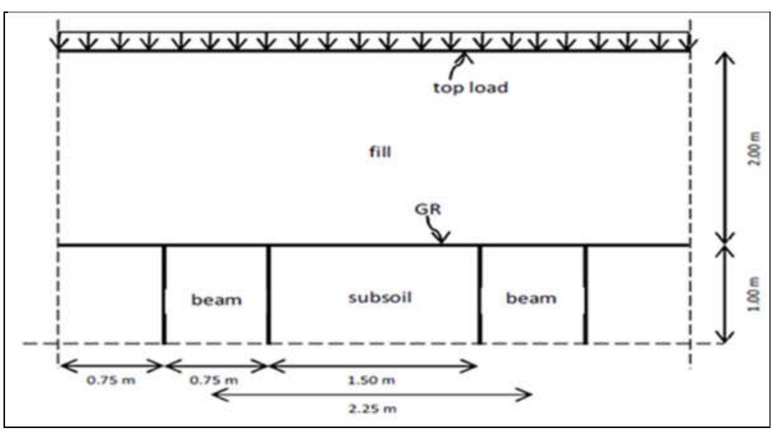

Figure Number 5. Modelled geometry [source: (9)]

C) Calculation phases

In the initial phase (Phase 0), the subsoil and beams are already in place (including the interfaces between them), but the GR and fill are not. Gravity loading is used to better account for the sudden border between beams and subsoil. In the next phase (Phase 1), when the embankment is built by activating the GR and fill (and all interfaces around the GR), the displacements are first set to zero. Phase 2 adds the top load, which means the entire geometry is active. In the last phase (Phase 3), the subsoil cluster is turned off to simulate a situation where the subsoil settles to an amount larger than the deflection of the GR. This leads to a subsoil support of zero and is realistic in case some sand or embankment fill is placed on top of the subsoil before placement of the GR. All calculation phases (leaving the initial situation) use a plastic analysis, which means the effect of consolidation is not included, but only the final situation of equilibrium. To take into account the change in stiffness and stress directions in the Geosynthetic Reinforcement upon deformation, the updated mesh option is turned on.

D) Mesh and Output-

Standard 15-node elements will be used. A geometry line will be added at the centre of the field between the two beams, from the GR upward to the top of the model. Also, two points will be added at the top centre of the beams. Plaxis automatically refines the structural elements (GR, Top load and interfaces).

3. RESULTS AND DISCUSSIONS

A basic 2d model with properties as mentioned in methodology was used to qualitatively and quantitaively validate the concentric arches model.

1. Qualitative Analysis
a. Modelled geometry

The modelled geometry after assigning of the materials is as shown in the figure below

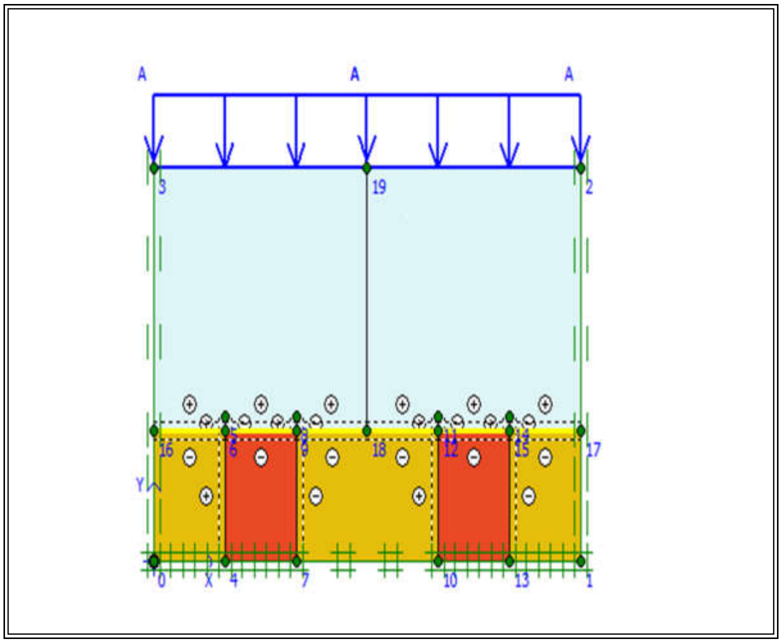

Figure Number 6. Modelled geometry in plaxis 2d.

b. Initial KO or Gravity Loading procedure

The initial K0 procedure to calculate the initial condition has to be done in plaxis 2d after generation of mesh is done as shown in the figure below

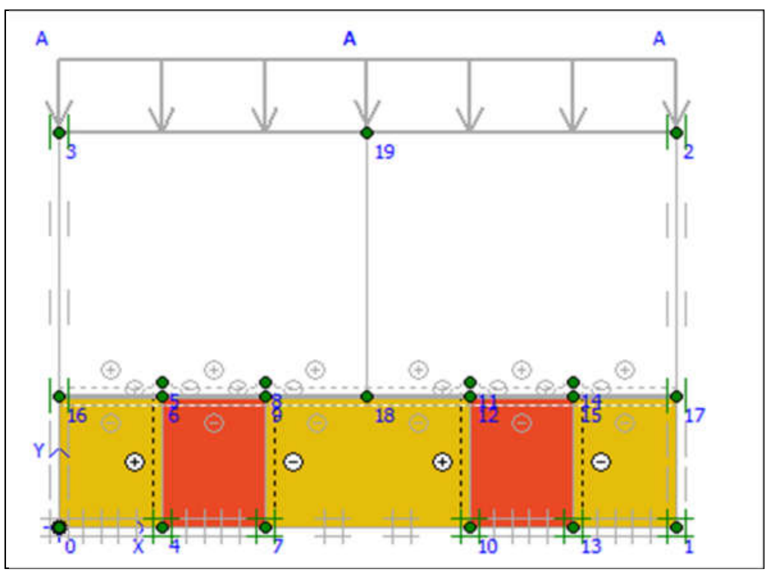

Figure Number 7. K0 or Gravity Loading procedure after mesh formation in plaxis 2d

c. Used calculaion phases in plaxis 2d

Table Number 2. Used calculation phases for basic 2d model

Serial Number	Phase name	Type	Activated geometry
1	Initial Phase	Gravity Loading	Beam,Subsoil
2	Build Embankment	Plastic (UM)	Beam,Subsoil,Embankment
3	Top loading	Plastic (UM)	Beam, Subsoil,Embankment,Top loading
4	Zero subsoil support	Plastic (UM)	Beam, ,Embankment,Top loading

d. Output of basic 2d model

The output considered for validation is only for the step 3 of calculation phase which considers absence of soft soil which gives realistic arching values.

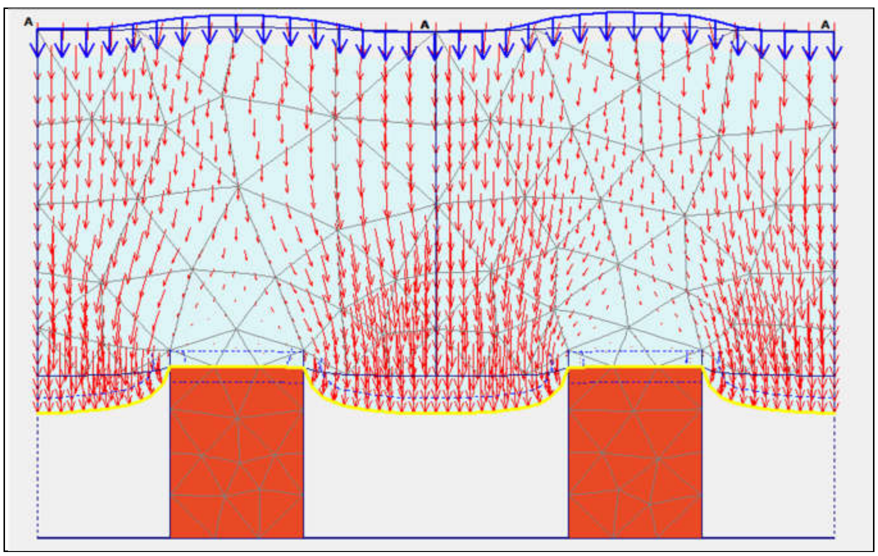

Figure Number 8. Output of basic 2d model

e. Arches formation (stress in principle direction)

The figure below shows the arches formed in the basic 2d model

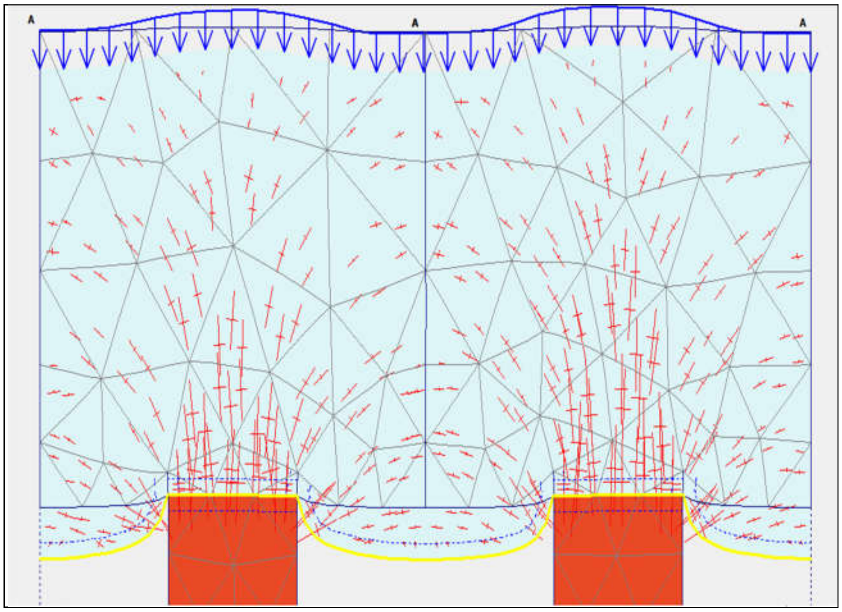

Figure Number 9. Arches formation in basic 2d model

The arches formed as shown in the figure 9 above shows the qualitative analysis of the concentric arces formed. From the figure it can be seen that small arches are formed in between the piles which are elliptical in nature as mentioned in zaeskes model but this arches are forming within the piles as told in the concentric arches model.

2. Quantitaive Analysis: distribution of loads and stresses

The quantitaive analysis which would confirm the validation of the concentric arches model can be done considering stress integration of points over the surface under consideration. The group of points which are considered for integration are as follows

- The stress points slightly above the top surface of piles,giving the arching force A
- The stress points slightly below the top surface of piles,giving the beam force A+B, thus giving the GR force B

As in phase 3 subsoil is not considered hence the force B+C was not considered. The value obtained by integrating the stress points to grt the arching force is compared with that obtained by the concentric arches model. The calculation by concentric arches model is as shown in the table below

Table Number 2. From 2D line Equations of concentric arches model of van enkelen[source(8)]

Number	As per Van enkelen [9]	Unit	Value
1	$Kp = \frac{1+sin\varphi}{1-sin\varphi}$	-	3.695
2	$Q2D = Kp\frac{\gamma}{Kp-2}$	kN/m^3	37.06
3	$Hx2gd = \frac{Sx}{2}$ for $H \geq \frac{1}{2}(Sx-a)$	m	1.125

4 $Lx2D = Sx-a$	for $H > \frac{1}{2}(Sx-a)$	m	1.5
5	$P2D = Kp.Hxg\,2D^{1-Kp}\,[\gamma H + p - \gamma Hxg2D.\,\frac{(Kp-1)}{(Kp-2)}$	kpa/m	23.1
6	$F_{GSTRIP} = [\frac{\gamma H+p}{\gamma H}][2.\frac{P2D}{Kp}(\frac{1}{2}.Lx2D)^{Kp} + \frac{1}{4}Q2D.\,Lx2D^{2}$	kN/pile	28.88
7	$A = Fpile = (\gamma H + p)Sx - F_{GSTRIP}$	kN/pile	58.62
8	$A\% = \frac{A}{(\gamma H+p).sx}$	**%**	**67**

The arching for part A for basic 2d model with surcharge of 5 kN/m2 is 67% for fill friction angle of 35 degrees. The same is compared with numerical calculation for phase 3 done by palxis 2d which is as shown in table below

Table Number 3. Values from basic plaxis 2d

Serial Number	From plaxis 2d	Unit	Value
1	A	kN/pile	59.89
2	A%	%	69%

The values obtained from both numerical method and by concentric arch equations can validate the model numerically from the values of the tables 3&4 above.

4. CONCLUSIONS

Thus the validation of concentric arches model in Indian condition using basic constitutive models of plaxis 2d can yield results which are satisfactory. More satisfactory results can be obtained by analysing 3d condition as stated by Vanpreet [9] .The 3d hemisphere as explained by Van enkelen [8] transfers load to the 2d arches in the front which yields better results with plaxis 3d analysis.

5. REFERENCES

[1] *K. Terzaghi, Theoretical Soil Mechanics, Wiley, New York, NY, USA, 1943.*

[2] *Kang Fei, Hindawi Publishing Corporation The Scientific World Journal,Volume 2014, Article ID 273253, 9 pages*

[3] *Van Eekelen, S.J.M., Bezuijen, A., Lodder, H.J., van Tol, A.F., 2012a. Model experiments on piled embankments Part I. Geotextiles and Geomembranes 32: 69-81*

[4] *Van Eekelen, S.J.M., Bezuijen, A., Lodder, H.J., van Tol, A.F., 2012b. Model experiments on piled embankments. Part II. Geotextiles and Geomembranes 32: 82-94 including its corrigendum: Van Eekelen, S.J.M., Bezuijen, A., Lodder, H.J., van Tol, A.F., 2012b2.*

[5] *Corrigendum to 'Model experiments on piled embankments. Part II' [Geotextiles and Geomembranes volume 32: 82-94]. Geotextiles and Geomembranes 35: 119.*

[6] *Van Eekelen, S.J.M., Bezuijen, A., 2012a. Inversed triangular load distribution in a piled embankment, 3D model experiments, field tests, numerical analysis and consequences, EuroGeo5, Valencia, Spain.*

[7] *Van Eekelen, S.J.M., Bezuijen, A. 2012b. Model experiments on geosynthetic reinforced piled embankments, 3D test series. In: Proceedings of Eurofuge, Delft.*

[8] *Van Eekelen, S.J.M., Bezuijen, A. van Tol, A.F., 2013. An analytical model for arching in piled embankments. Geotextiles and Geomembranes 39: 78-102.*

[9] *Van der Peet, Validating and analysis of new design method for piled embankment with plaxis 2D and 3D, www.plaxis.com, Autumn issue 2014,Plaxis Bulletin*

[10] *Hewlett, W. J., & Randolph, M. F. (1988). Analysis of piled embankments. Ground Engineering, 21(3), 12-18*

[11] *Liu, H. L., Ng, C. W. W. and Fei, K. (2007). Performance of a geogrid-reinforced and pile-supported highway embankment over soft clay: Case study, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 133(12), pp. 1483-1493.*

[12] *Li, A. L. and Rowe, R. K. (2008). Effects of viscous behaviour of geosynthetic reinforcement and foundation soils on the performance of reinforced embankments, Geotextiles and Geomembranes,Vol.26,pp.317-334*

[13] *Priyanath Udayanga Ariyarathne(2015). Numerical Modelling Of Geosynthetic Reinforced Pile-Supported Embankments, Thesis (phd)-University of Western Sydney.*

[14] *A Bhasi and Prof. Rajagopal(2014). Numerical Modelling and Analysis of Geosynthetic Reinforced Pile supported Embankments, Recent Researches in Engineering mechanics,Urban and Naval Transportaion and Tourism,pp 158-162*

[15] *Plaxis 2D manual Reference, Tutorial, Examples.(Version 8.2).*

[16] *L A Masursky (2006). Three Dimensional Analysis of GEosynthetic Reinforcement used in Column Supported structure, Thesis (Msc)-Virginia Polytechnic Institute and State University*

[17] *IRC 113: "Guidelines for the /deisgn and Construction of Geosynthetic Reinforced Embankments on Soft Subsoils",2013*

[18] *12_Chapter 4 shodhganga, Shodhganga.infibnet.ac.in*