Civil and Environmental Research
ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online)
Vol.3, No.3, 2013
www.iiste.org

A Study of Seepage through Oba Dam Using Finite Element Method

Kolawole Adisa Olonade (Corresponding Author)
Department of Civil Engineering, Obafemi Awolowo University
Ile-Ife, Nigeria
Tel: +234-70-36439726; E-mail: makkolawole@yahoo.com

Oluwole Akinyele Agbede
Department of Civil Engineering, University of Ibadan, Nigeria

Tel: +234-80-33847722; E-mail: oaagbede@yahoo.com

Abstract
Dams are constructed to impound water for flood control, water supply, irrigation, energy generation, recreation as well as pollution control. Yet destructive effects of water on them are enormous. Seepage has been implicated as a major cause of dam failure due to its potential to cause internal eruption of soil. Different methods have been identified to study the extent of seepage in earth dams. Of the methods, flow net is commonly used due to its relative simplicity. However, it becomes more complex with zoned earthfill dams. In this paper, Finite Element Method (FEM) is employed to study seepage behaviour in Oba dam. Though the method was developed for the analysis of aircraft structural problems, due to its versatility, it is found as tool to solve variety of other practical problems. Finite Element formulation of the governing equation was established and computer programme was written to solve it. The bottom of the dam was meshed using rectangular element mesh while the piezometric heads at nodal points were determined. Also, determine was the coordinates that define the phreatic surface of the seepage. The results obtained were compared with those obtained from flow net approach which served as control using t-Test technique. It was observed that there was no significant difference ($p > 0.0005$) between the results. Thus, the method is appropriate for the study. The added advantage of the FEM is that simulation of the seepage problem of the dam becomes easy.

Keywords: Finite Element, seepage, Oba dam, piezometric head, phreatic surface.

1.0 Introduction

Dams are constructed for specific purposes, such as hydropower, navigation, flood control, water source, or recreation. Despite the fact that dams hold water for future use, the destructive effect of water on dams is enormous. History reveals that mankind has feared and respected the destructive power of water. B.S. Thandaveswara (2009) collated cases of dam failure in some countries and their untold damages they cause.

A number of factors have been identified as causes of dam failure. Punmia and Lal, (1992), attributed 40% of failure to Hydraulic, 30% to seepage while structural failure carried the remaining 30%. In his study Arora, (2001) also showed that about 35% of failures of earth dams are due to hydraulic failures, about 30% are attributed to seepage failures and about 20% are as a result of structural failure. The remaining 7% of the failures are due to other miscellaneous causes such as accidents and natural disasters.

All dams have some seepage as the impounded water seeks paths of least resistance through the dam and its foundation. Seepage becomes a concern if it is carrying material with it, and should be controlled to prevent erosion of the embankment, or foundation, or damage to concrete structures (National Dam Safety Program Research Needs Workshop, 2006).

Researchers have evolved different methods to study and monitor seepage in dams in order to forestall intending failure. Such methods include analytical, electric analogy and flow net (Ali, S., and Fardin, 2005; Abdullahi et.al, 2000, and Casagrande, 1961). Billstein et al. (1999) used experimental models to determine discharge, pore water pressure, seepage face and free surface profile. More recently, FEM is being used. Several authors such as Papagianakis and Fredlund (1984), Lam et al (1988), Potts and Zdravkovic (1999), Darbandi et. al. (2007) and Rushton and Redshaw (1979) had performed seepage analysis through an embankment dam using finite element method. Also, Agbede (1989) presented a computer simulation of the groundwater flow through a porous medium in the Northern State of Nigeria.

Oba dam is located at the University of Ibadan, Nigeria. Since the movement of the university to its present site, the water supply within the university had been erratic until Oba dam was built across Oba river in 1972. The dam is located at the southeastern fringe of the university campus between sokoto road and the road leading to the Vice-Chancellor's lodge.

It was constructed of earthen materials of length 110 m with height 8.5 m. The estimated maximum length and depth of the pool were 700 m and 8.5 m respectively in the normal period of non-flood while the maximum capacity water impounded was 227 million litres.

As at the time of study, there was no functional facility to monitor seepage history of the dam. Being an earth dam, it was susceptible to seepage and taken into consideration its immense importance to the university community. Thus, choosing it as a case study was worthwhile.

2.0 Methodology

2.1 Geological and Geophysical study

Geological and geophysical studies of the dam embankment were investigated. Parameters measured were layer resistivity and thickness, coefficient of permeability. Compaction and soil characteristics were equally examined. The method described by Telford, et al., 1990 was followed.

2.2 Meshing of the bottom of the dam

The bottom of the dam was meshed into 133 rectangular shaped elements with 160 nodal points (Figure 2.1).

2.3 Finite Element formulation for the steady state of seepage flow

In 2-dimensional steady state anisotropic seepage flows are:

$$V_x = -k_x \, \partial h / \partial x$$
$$V_y = -k_y \, \partial h / \partial y \qquad 2.1$$

For isotropic $k_x = k_y$

During seepage, continuity condition is satisfied (i.e. inflow = outflow). This is represented in equation 2.2

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} = 0 \qquad 2.2$$

substituting velocities in terms of heads, the equation becomes

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} = 0 \quad in\, \Omega \qquad 2.3$$

For a 2-dimensional domain Ω. The boundary conditions are

$$h = \bar{h} \quad on\, \Gamma_g \quad and \quad \frac{\partial h}{\partial n} = \bar{q} \quad on\, \Gamma_n \qquad 2.4$$

$\bar{h}$ *and* $\bar{q}$ denote known variable and flux boundary conditions. n, in equation 2.4, is the outward normal unit vector at the boundary. Γ_g *and* Γ_n are boundaries for essential and natural boundary conditions, respectively.

For the well posed boundary value problem,

$$\Gamma_e \cup \Gamma_n = \Gamma \qquad 2.5$$

and

$$\Gamma_e \cap \Gamma_n = \emptyset \qquad 2.6$$

in which $\cup$ *and* $\cap$ denote sum and intersection respectively, and Γ is the total boundary of the domain Ω.

Integration of weighted residual of the differential in equation and boundary condition is

$$I = \int_{\Omega} w\left(k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial x^2}\right) d\Omega - \int_{\Gamma_e} w \frac{\partial h}{\partial n} d\Gamma \qquad 2.7$$

The weak formulation for equation (2.7) as described by Kwon and Bang, 2000 is given as

$$I = \int_{\Omega} \left(k_x \frac{\partial w \partial h}{\partial x \partial x} + k_x \frac{\partial w \partial h}{\partial y \partial y}\right) d\Omega + \int_{\Gamma_n} w \frac{\partial h}{\partial n} d\Gamma \qquad 2.8$$

The first volume integral becomes a matrix term while the line integral becomes vector terms.

This gives the relationship between material stiffness $[k]$, quantity of flow $[Q]$ and the nodal piezometric head $[h]$, which can be expressed as a set of simultaneous equations as

$$[k][h] = [Q] \qquad 2.9$$

2.4 Determination of nodal heads and coordinates of phreatic surface

In solving equation 2.9 to determine nodal heads and phreatic surface coordinates, computer programme (SEEP2D1 and SEEP2D2), using FOTRAN 90 language, was written and ran.

2.4.1 Input data for the programs

- **SEEP2D1**
  - i. Number of nodal points
  - ii. Number of elements
  - iii. Number of gauss points
  - iv. Coordinates of the nodal points at the lower and upper boundaries.
  - v. Heads at the boundary nodes
  - vi. Nodal points of the boundary elements where Q=0.
  - vii. The number of nodes that made up an element.
  - viii. Materials permeabilities in both x and y axes.
- **SEEP2D2**
  - i. Width of the dam the base
  - ii. Inclination of left slope (degrees)
  - iii. Inclination of right slope (degrees).
  - iv. Upstream water level (m)
  - v. Downstream water level (m).

2.4.2 Boundary Conditions

From Figure 2.1, the boundary conditions for the problem were:

$h_8 - h_{16} - h_{24} - h_{32} - h_{40} - 5500$

$h_{128} = h_{136} = h_{144} = h_{152} = h_{160} = 0$

$q = 0$ on the boundary 1-8
on the boundary 153-160
on the boundary 1-153
on the boundary 48-120

Total number of isoparametric elements = 133

Total number of nodal points = 160
The assemblage matrix size = 150 X 160

2.5 Conventional Method – Flow net
Flow net diagram were drawn for seepage under the dam and through the dam. Thereafter, the piezometric heads were determined at each nodes (Figure 2.1) using the method described by Casagrande (1925). Also determined were the coordinates of the flow line (phreatic surface) for the seepage through the dam. Figure 2.2 shows the flow net and phreatic surface.

2.6 Comparison between FEM and Flow Net results
The results obtained in 2.3 and 2.4 were compared by testing for any significant difference. Descriptive statistics and t-test were conducted using SPSS statistical software.

3.0 Results and Discussion
3.1 Geological and geophysical properties of the dam embankment
The geological survey of the embankment revealed that the lithology of the bedrock within the dam area and beyond (up to 50 m) was quartzite schist while the material from the embankment was 'hard' near the surface (N = 30) to very 'stiff' clay material below and between 3.0 m – 8.0 m (N = 15 – 30). The dam had no cit-off as part of its foundation. The implication of this was that the dam embankment was well compacted to prevent high degree of seepage. Furthermore, the coefficient of permeability in both directions (X– and Y- axes) was $1.2 \times 10^{-5}\, cm/s$. This showed that the material from which the embankment was made was isotropic.

In Table 3.1, the summary of geophysical properties of the dam embankment area and Oba river catchment area are presented. The layer resistivities varied with layer thickness with low resistivity at the 1st layer (top soil) for the two areas (dam embankment and river catchment area) indicating that they consisted of loose sandy soil with traces of clay. However, the resistivity became infinity at the third and fourth layers for dam embankment and river catchment areas respectively showing that the layer were of hard basement (bedrock). There were relatively low resistivity at 2nd and 3rd layers of the river embankment areas; these layers were suspected to have been fractured or weathered. The same reason may be responsible for the low resistivity at the 2nd layer (10.0 - 13.1 m) in the dam embankment area.

3.2 Nodal heads and Coordinates of the phreatic surface
Potential heads at the 160 nodes of the element mesh were determined from the program SEEP2D1. Figure 3.1 shows the array of the potential heads at various nodes as determined from the program. It is observed that the potential heads reduce with the depth indicating that the surface of the dam is more prone to seepage when compared to the base. Also, at the downstream surface, the nodal head is zero (node 160) but increased to 335 at node 153. This is an indication that seepage is suspected through the foundation of dam embankment. These results were compared with those obtained from flow net approach. Table 3.2 shows the results of the statistical analysis conducted on the results. Due to the means of the two results and the magnitude of t-value [$t(159) = 0.349$, $p > 0.005$], it can be concluded that there was no statically significant difference in the potential heads obtained from FEM as compared to those of flow net.

Coordinates (x,y) that define the phreatic surface (flow line) as obtained from FEM is plotted and compare to that obtained from flow net (Figure 3.3). As can be seen the graphs are not significantly different from each other. The direction of the graphs depict direction of flow of

water. Indicating flow from higher potential at nodes 8, 24, 32 and 40 (Figure 2.2) to lower potential at nodes 128, 136, 144, and 152 across the dam embankment. It can be deduced that both FEM can be used as tool to monitor seepage in earth dams.

Conclusion

1. Finite Element Method (FEM) was used to determine the potential heads at 160 nodal points. The method was equally employed to obtain coordinates of the flow line through the dam. These were repeated with the

use of conventional method (flow net method).

2. The finite element program (SEEP2D1 and SEEP2D2) can be used to monitor seepage in homogeneous and isotropic earth dams as applied to Oba dam. The results obtained using FEM were comparable perfectly with those obtained from flow net approach [$t(159) = 0.349$, $p > 0.005$).

References

Abdallah.L ,Makawi.H.,Mohanned Al-sheriaded (2000), 'Evaluation and rehabitiation of dam seepage problems,case study:kfrrein dam' ,*Journal of Engineerong Geology* ,Vol.56, pp.335-345.

Agbede, O.A. (1989). 'Computer simulation of groundwater flow through a porous media" Modelling, Simulation and Control, AMSE Press, Vol. 19, No.1 pp.11-26.

Ali, S., and Fardin, J.,(2005). "3D Steady State Seepage Analysis of Embankment Dams", *Electronic Journal of Geotechnical Engineering* (EJGE), Vol. 10, Bandle F.

Arora K.R.(2001). 'Irrigation Water Power and Water Resources Engineering'. Naisarak India: Standard Publishers.

Billstein, M., Sevensson, U., and Johansson, N.(1999). "Development and Validation of a Numerical Model of Flow through Embankment Dams - Comparisons with Experimental Data and Analytical Solutions", *Transport in Porous Media*, Vol. 35, No. 3, pp. 395-406.

Casagrande, A. (1961). "Control of Seepagr through foundations and abutments of dams", Geotechnique, Vol. XI, pp. 161-181.

Darbandi, M., Torabi S. O., Saadat, M., Daghighi, Y and D. Jarrahbashi (2007). 'A moving-mesh finite-volume method to solve free-surface seepage problem in arbitrary geometries' *Int. J. Numer. Anal. Meth. Geomech.* 2007; 31:1609–1629 Published online 30 April 2007 in Wiley Inter Science (www.interscience.wiley.com). DOI: 10.1002/nag.611

Lam, L., Fredlund, D.G., and Barbour, S.L(1979). "Transient seepage model for saturatedunsaturated systems: A geotechnical engineering approach." *Canadian Geotechnical Journal*. Vol. 24, No. 4, 1988, pp. 565-580.Rushton and Redshaw.

National Dam Safety Program Research Needs Workshop, 2006.

Papagianakis, A.T. and Fredlund, D.G. (1984), "A steady state model for flow in saturatedunsaturated soils." *Canadian Geotechnical Journal*. Vol. 21, No. 3, , pp. 419-430.

Potts, D.M. and Zdravkovic, L. (1999)., "Finite Element analysis in geotechnical engineering: Theory." Thomas Telford, Great Britain.

Punmia B. C. and Lal P. B. B. (1992). Irrigation and Water Power Engineering. 12th Ed. J. udpur India. Laxmi Pupblications (P) Ltd.

Rushton, K.R. and Redshaw, S.C., "Seepage and Groundwater Flow: Numerical Analysis by analog and digital methods." John Wiley & Sons, Great Britain, 1979.

Telford, W. M., Geldart, L. P., and Sheriff, R. E., (1990).' Applied Geophysics'. Cambridge University Press

Thandaveswara, B.S. (2009). 'History of dam failures', Indian Institute of Technology, Madras.

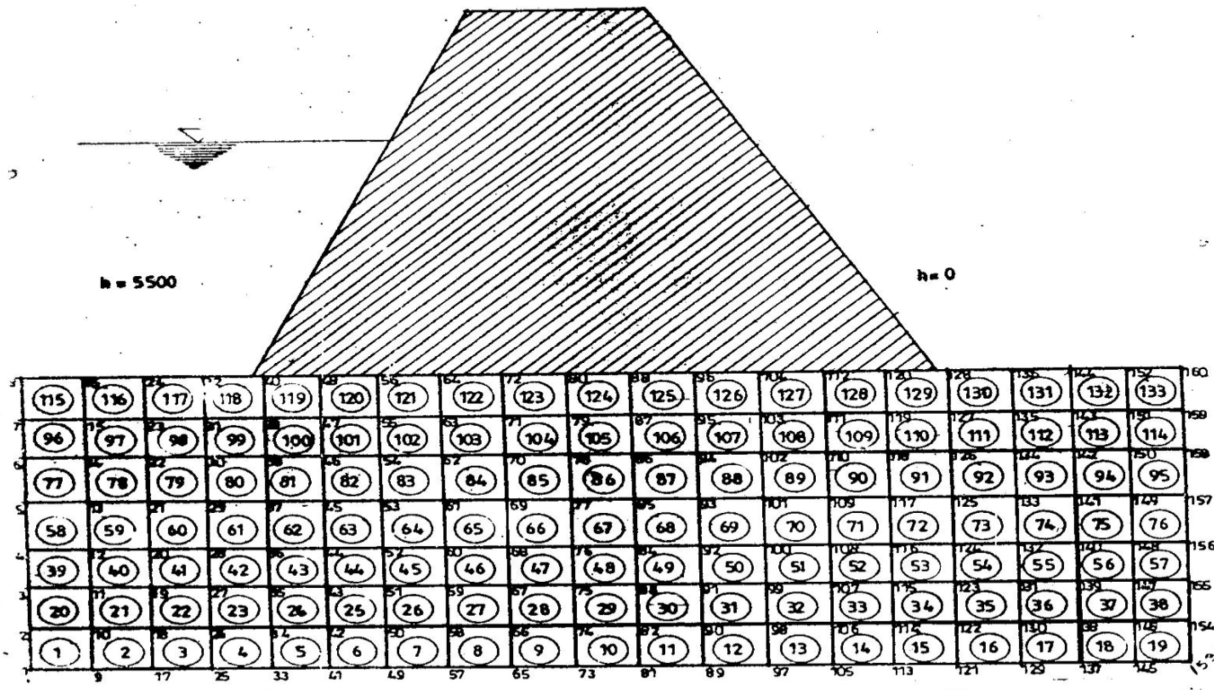

Figure 2.1: Region of seepage flow under the dam meshed into 133 elements with 160 nodal points.

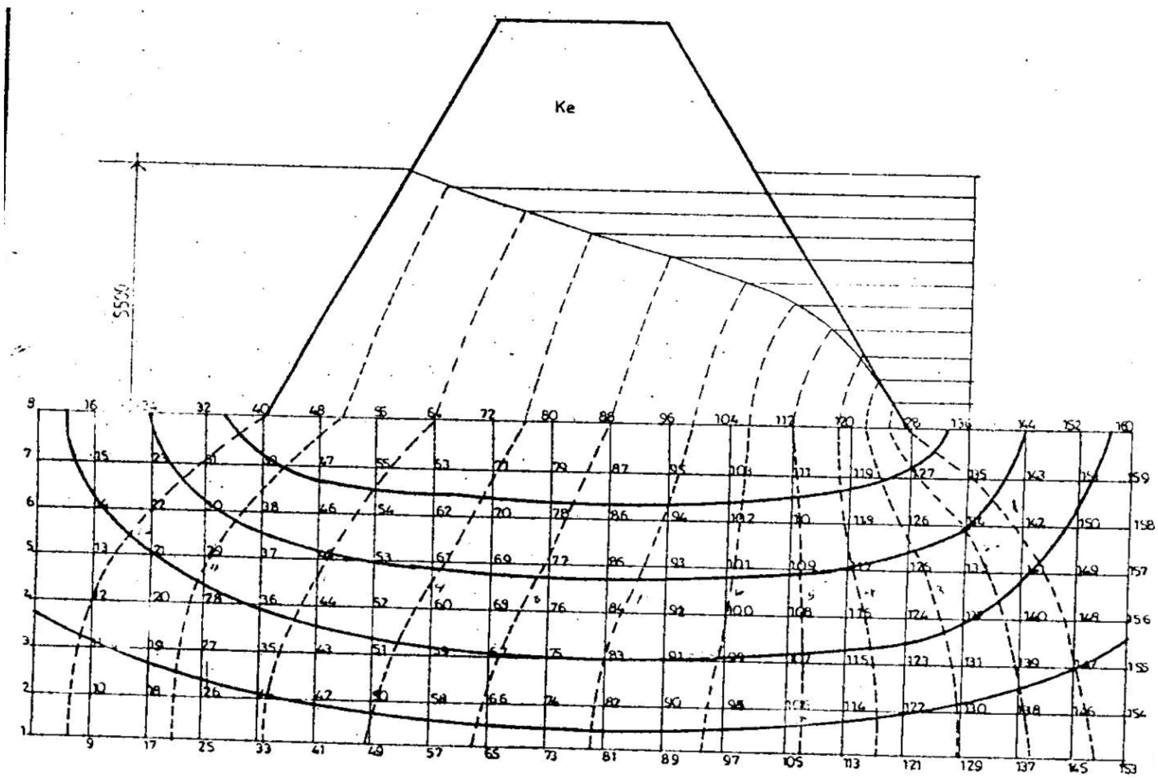

Figure 2.2: Flow net and phreatic surface through Oba dam

5500	5500	5500	5500	5500	4780	4480	4230	3975	3671	3375	3088	2700	2110	1600	0	0	0	0	0
5410	5370	5246	5030	4860	4565	4355	4100	3850	3590	3342	3040	2708	2112	1608	1010	460	330	169	120
5370	5245	5077	4360	4610	4400	4230	4010	3760	3510	3248	2960	2655	2110	1692	1225	840	420	250	165
5288	5160	4990	4700	4480	4155	4062	3892	3580	3375	3130	2870	2581	2155	1735	1390	1010	630	335	212
5265	5070	4860	4600	4400	4190	3975	3724	3550	3300	3040	2830	2538	2150	1820	1480	1140	760	425	254
5240	5030	4820	4612	4315	4100	3890	3630	3425	3170	2950	2740	2490	2200	1862	1523	1180	846	450	270
5200	4990	4780	4569	4273	4020	3810	3590	3380	3130	2950	2750	2450	2210	1900	1560	1220	885	580	335
5200	4990	4780	4570	4270	4020	3760	3590	3300	3130	2920	2700	2410	2200	1900	1523	1270	885	550	335

Figure 3.1: Potential heads at 160 nodal points

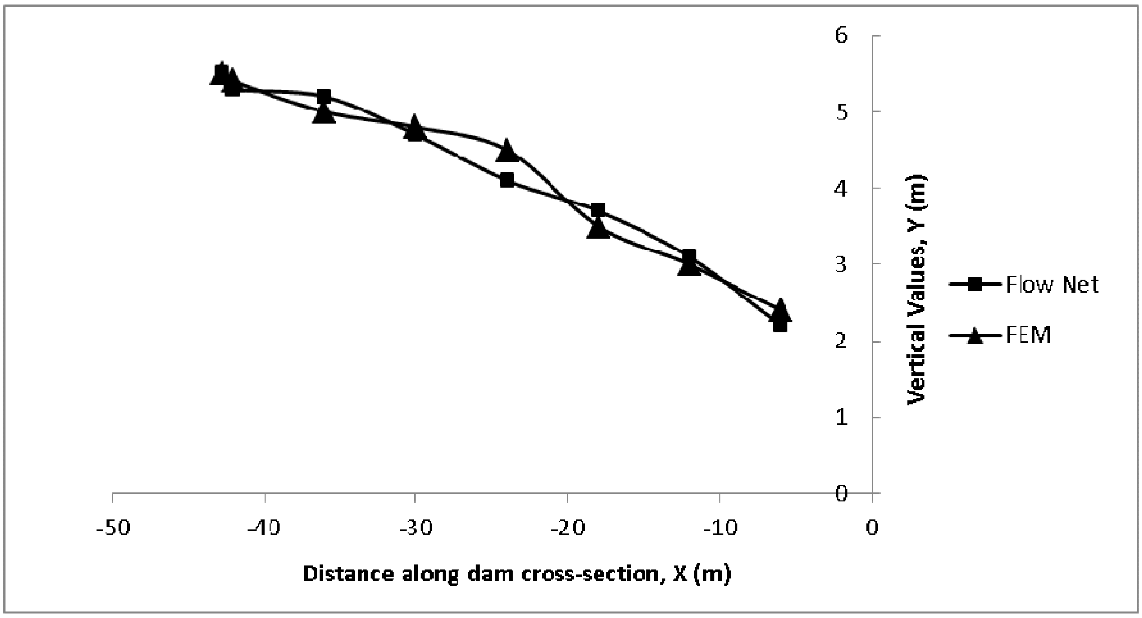

Figure 3.2: Phreatic surfaces obtained from FEM and Flow Net methods

Table 3.1: Geophysical properties of the dam embankment and river catchment area

Layer Level	Dam Embankment Area			Oba River Catchment Area		
	Layer Resistivity (Ωm)	Layer Thickness (m)	Soil composition	Layer Resistivity (Ωm)	Layer Thickness (m)	Soil composition
1st Layer	190 – 460	0.6 – 2.8	Sandy-clay	80 – 1500	0.6 – 3.5	Sandy-clay
2nd Layer	15 - 80	10.4 – 13.1	Clay, sandy-clay and silt	12 – 490	3.5 – 24	Clay and silt
3rd Layer	∞	13.2 – 14.2	Rock	35 - 878	24.0 – 36.4	Clay and silt
4th Layer	na	na	na	4551 - ∞	> 36	Rock

* na – not available

Table 3.2 Paired Samples test between FEM and Flow net results

			Pair 1 FEM – Flow Net
Paired Differences	Mean		0.050
	Std. Deviation		1.811
	Std. Error Mean		0.143
	95% Confidence Interval of the Difference	Lower	-0.233
		Upper	0.333
t			0.349
df			159
Sig. (2-tailed)			0.727