Study of Displacement Distribution Around Circular Opening Affected by Presence of Discontinuities Using Laboratory Biaxial Test

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Abstract

Displacement of the opening could be affected by applied stress conditions (k, is ratio between the horizontal stress to the vertical stress), the presence of discontinuity around opening, and also properties of both rock and joint. The displacement of the opening affected by presence of discontinuities could not be estimated analytically. Therefore biaxial test could be used to study the distribution of displacement around the opening with the approach of physical models and numerical models. Physical models were made of a mixture of cement and sand, with dimension of 45 cm x 45 cm, radius circular opening of 4.5 cm, thickness of 30 cm, and persistence of discontinuities of 25 cm. Whereas the numerical models was using finite element 3D method and utilizing the Rocscience 3 software (by Rocscience). Opening models were made, among others: opening without discontinuity, opening with dip discontinuities 0°, opening with dip discontinuities 90°, and opening with dip discontinuities 45°. Biaxial test performed by applying a stress to the model in the horizontal and vertical direction to reach the plane strain condition. Stress conditions applied varies in k = 1/2, k = 1, and k = 2, with vertical stress σ_v = 0.84 MPa. The displacements were measured at wall opening (1R) using dial gauge (accuracy 1 μm) and around the opening (2R and 3R) using strain gauge (accuracy 0.01 μm). Displacement measurement results were compared with the results of numerical modeling. Overall, the great displacement occurred at the wall of opening, with stress condition k = 2. In this research, the filling material of joint strengthen the opening models. However, numerical model could not yet explain the physical model, so further studies need to be done.

Keywords: Displacement, Circular Opening, Biaxial Test.

1. Introduction

Displacement of the opening could be affected by applied stress conditions. Stress conditions applied varies depend on the ratio between the horizontal stress to the vertical stress (k). Displacement of the opening could also be affected by the properties of the rock mass in which openings are made, and the presence of discontinuities around opening. To understand the effect, then the research has be done by make some opening models. The methods that can be used to identify and analyze the distribution of displacements and stresses around the hole openings are physical model approaches and numerical method. In this research, a physical model approach (cement and sand) is used, as well as a numerical method using the finite element method with the help of software Rocscience 3 (Rocscience).

2. Physical Model

2.1 Physical Properties

Material physical model used in this study is a concrete comprising a mixture of cement and sand in the ratio 1 : 3. The physical model is created consisting of 4 (four) kinds of opening namely without discontinuities, with discontinuities dip 0°, 90°, and 45°. The dimensions of the physical models of any openings or tunnel can be seen in Table 1.

Table 1 The dimensions of each openings

Kinds of Opening	Model	Size of sample (*l x w x h*)	Radius of openings (*r*)
		cm	cm
Without discontinuities	I	45 x 45 x 30	4.5
Discontinuities dip 0°	II	45 x 45 x 30	4.5
Discontinuities dip 90°	III	45 x 45 x 30	4.5
Discontinuities dip 45°	IV	45 x 45 x 30	4.5

Table 2 Physical Properties of Model

Physical Properties	Unit	Value for Rockmass
Natural Density	gr/cm^3	2,07
Ultrasonic Velocity	m/s	1.996,24
Young's Modulus	MPa	850,38
Young's Modulus (back analysis)	MPa	235
Poisson's Ratio	-	0,36
UCS intact rock	MPa	3,37
m_b	-	6,36
s	-	0,108
a	-	0,500593

2.2 Loading Conditions

Testing any physical model is done by loading σ_v= 0,84 MPa with conditions ratio σ_h to σ_v (k) varies namely k = ½, k = 1, dan k=2. This loading value is obtained by calculating the elastic properties based on stress – strain curve of uniaxial compressive strength test.

2.3 Biaxial Tests

Biaxial tests is the done by providing two-way loading on the x-axis and y-axis. This loading is done in the hope of plane strain condition can be achieved, which by giving the loading on x and y axis, the displacement will occur in the direction of x and y axis, whereas the displacement in the z-axis direction becomes so small that can be ignored. Furthermore, the displacement at the points of measurement has been determined on a physical model of openings experiencing biaxial loading can be seen from the results of a direct reading on the dial gauge and data of displacements from the strain gauge are recorded by data logger (branded Dewe43).

In the biaxial testing, displacement at wall opening (1R) was measured with a dial gauge, while the displacements at around opening (2R and 3R) are measured with a strain gauge rosette type. Dial gauge and strain gauge installed to the points of measurement specified in each physical models, with a caption that angle of 0° describes the position of right wall opening, while the angle of 90° describes the position of roof opening.

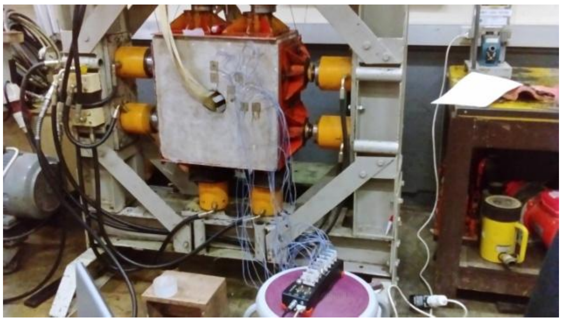

Fig. 1 Biaxial Test

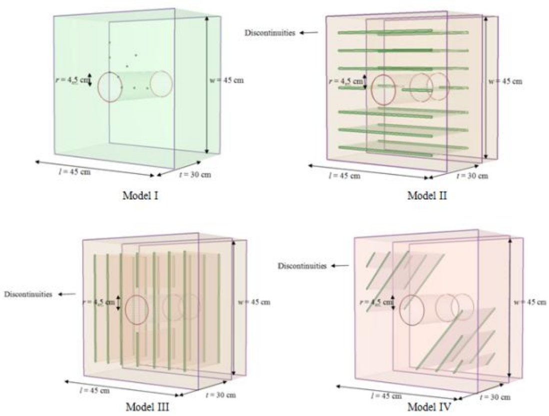

Fig. 2 Models of opening

3. Data and Discussion

Table 3 shows the displacement distribution of physical and numerical modeling on the opening without discontinuities.

Table 3 Displacement distribution of physical and numerical modeling on the opening without discontinuities

k	Angle (°)	Displacement (mm)						Average difference between 2R and 3R (%)
		Physical			Numerical			
		1R	2R	3R	1R	2R	3R	
1/2	0	0.03	8.2	5	8.0	6.5	5.0	20.61
	45	0.07	6.7	4.5	7.3	5.9	4.6	11.9
	90	0.09	5.0	0.3	5.3	4.3	3.7	7.04
1	0	0.08	7.8	5.0	8.1	6.5	5.0	16.67
	45	0.08	7.6	4.3	7.4	5.9	4.5	13.41
	90	0.08	5.3	0.4	5.5	4.4	3.6	52.98
2	0	0.18	10.8	10.4	13.8	11.1	8.4	10.97
	45	0.14	8.7	2.4	10.5	8.4	6.6	33.54
	90	0.06	5.1	0.6	6.1	4.6	4.3	47.92

At the condition *k* = 1/2, the displacements at 2R in the physical model are greater than the displacements in the numerical model. Then the displacements at 3R in the numerical model approach the displacements in the physical model, except at angle 90° where the displacement in numerical model is greater than the physical model.

At the condition *k* = 2, the displacements at 2R in numerical model approach the displacements in physical model. However, the displacements at 3R in the physical model are different with the displacement in numerical model.

Table 4 Displacement distribution of physical and numerical modeling on the opening with discontinuities dip 0°

k	Angle (°)	Displacement (mm)						Average difference between 2R and 3R (%)
		Physical			Numerical			
		1R	2R	3R	1R	2R	3R	
1/2	0	0.1	5.6	5.4	2.5	2.3	2.4	58.93
	45	0.0	3.3	3.0	2.1	1.4	0.7	67.12
	90	0.0	1.2	0.6	2.1	1.5	1.4	38.57
1	0	0.1	6.6	5.2	3.1	3.2	3.4	43.07
	45	0.0	2.3	4.8	2.7	2.2	1.8	33.43
	90	0.0	1.5	1.0	2.6	1.8	1.1	12.88
2	0	0.1	6.4	3.4	3.1	2.9	2.9	35.53
	45	0.1	2.7	1.7	2.8	2.2	1.9	14.53
	90	0.0	1.4	1.2	2.8	2.1	1.5	26.67

Table 4 shows the displacement distribution of physical and numerical modeling on the opening with discontinuities dip 0°.

At the condition k = 1, seen anomaly in the physical model where the displacement at 2R angle of 45° is smaller than the displacement at 3R angle of 45°. This can occur because of the position of the measurement point at 3R angle of 45° lies in a weak field. It points out that the condition k = ½ and k = 1, the displacement between the physical model and numerical model have differences.

At the condition k = 2, the displacements at 3R in the numerical model approach the displacements in the physical model. But at the other measurement points, there are differences between the displacements in the physical model and numerical model.

Table 5 Displacement distribution of physical and numerical modeling on the opening with discontinuities *dip* 90°

k	Angle (°)	Displacement (mm)						Average difference between 2R and 3R (%)
		Physical			Numerical			
		1R	2R	3R	1R	2R	3R	
1/2	0	0.1	4.4	2.9	3.2	2.6	2.3	30.80
	45	0.04	3.6	2.6	1.8	1.2	1.3	58.34
	90	0.0	0.98	2.5	1.7	0.9	0.9	36.88
1	0	0.1	7.8	3.1	3.7	2.8	2.4	43.34
	45	0.04	3.3	2.9	1.8	1.4	1.1	59.67
	90	0.0	2.8	1.0	1.9	1.4	1.1	29.55
2	0	0.1	4.7	2.4	1.2	0.9	0.6	77.93
	45	0.04	3.9	2.0	1.6	1.2	1.0	58.87
	90	0.0	3.6	0.6	3.2	2.3	1.6	49.42

Table 5 shows the displacement distribution of physical and numerical modeling on the opening with discontinuities dip 90°. In the numerical model for all k conditions, displacements at 1R are larger than the displacements at 2R and 3R in each point of measurements.

At the condition k = 1/2, the displacements at 2R and 3R in the numerical model have small differences with the physical model. At the condition k = 1, the displacements at 2R in the numerical model are smaller than the displacements in the physical model. However, the displacements at 3R in the numerical model approach the displacements in the physical model, especially at an angle of 0° and 90° where the displacements in the physical models and numerical models have the same value. At the condition k = 2, the displacements at 2R in the numerical model are smaller than the physical model, while the displacements at 3R numerical model are also relatively smaller than the physical model, but the differences are not much.

Table 6 Displacement distribution of physical and numerical modeling on the opening with discontinuities *dip* 45°

k	Angle (°)	Displacement (mm)						Average difference between 2R and 3R (%)
		Physical			Numerical			
		1R	2R	3R	1R	2R	3R	
1/2	0	0.1	2.1	-*	2.4	1.8	-*	14.29
	45	0.4	2.1	1.5	2.8	2.2	1.9	25.60
	90	0.05	1.7	1.1	1.6	1.3	1.6	27.39
	135	2.5	4.0	1.6	3.4	2.7	2.0	26.25
	180	1.6	2.5	-*	3.2	2.5	-*	0.0
1	0	0.1	1.6	-*	3.1	2.5	-*	36.0
	45	0.5	1.6	0.6	2.3	1.8	2.1	41.27
	90	0.05	1.5	0.4	1.7	1.4	1.9	42.81
	135	2.4	3.4	1.5	3.6	2.8	2.1	23.11
	180	1	2.2	-*	3.5	2.8	-*	21.43
2	0	0.05	1.2	-*	4.1	3.3	-*	63.64
	45	0.1	1.3	0.5	1.8	1.7	1.4	43.91
	90	0.01	1.1	0.3	1.4	0.8	0.4	48.32
	135	2.1	3.6	1.0	3.3	2.8	2.5	41.21
	180	0.5	1.5	-*	1.9	1.7	-*	10.18

*not be measured

Table 6 shows the displacement distribution of physical and numerical modeling on the opening with discontinuities dip 45°.

At the condition k = 1/2, the displacements at 1R in the physical model approach to the numerical model at an angle of 135° and 180°, but it can be seen that the displacements in 1R in numerical model are greater than the physical model. While the displacements at 2R on numerical model are relatively equal to the displacements in the physical model, except at an angle of 135° in which the displacements in the numerical model are smaller than the physical model. Then the displacements at 3R in the numerical model approach to the physical model.

At the condition k = 1, the displacements at 1R in the physical model are smaller than the numerical model. While the displacements at 2R in the numerical model relatively have the same value with the physical model. But the displacements at 3R in the numerical model are greater than the physical model.

At the condition k = 2, the displacements at 1R in the physical model are smaller than the numerical model. While the displacements at 2R in the numerical model relatively equal to the physical model except at an angle of 0° where the displacement in the numerical model is greater than the physical model. For the location at 3R, the displacements in the numerical model are greater than the physical model except at an angle of 90° in which the displacement in the numerical model and the physical model are same.

In the numerical model for all k conditions, the displacements at 1R and 3R are greater than the displacements at 1R and 3R in the physical model.

In the physical model for all k conditions, the displacements at 2R are greater than the displacements at 3R for each angle measuring point. In the physical model of opening with discontinuities dip 45°, the displacements at 1R is read on the dial gauge has considerable value at an angle of 135 ° and 180 °, it can be occur due to the displacements are large enough for their discontinuities so that it can read by the dial gauge measuring instrument.

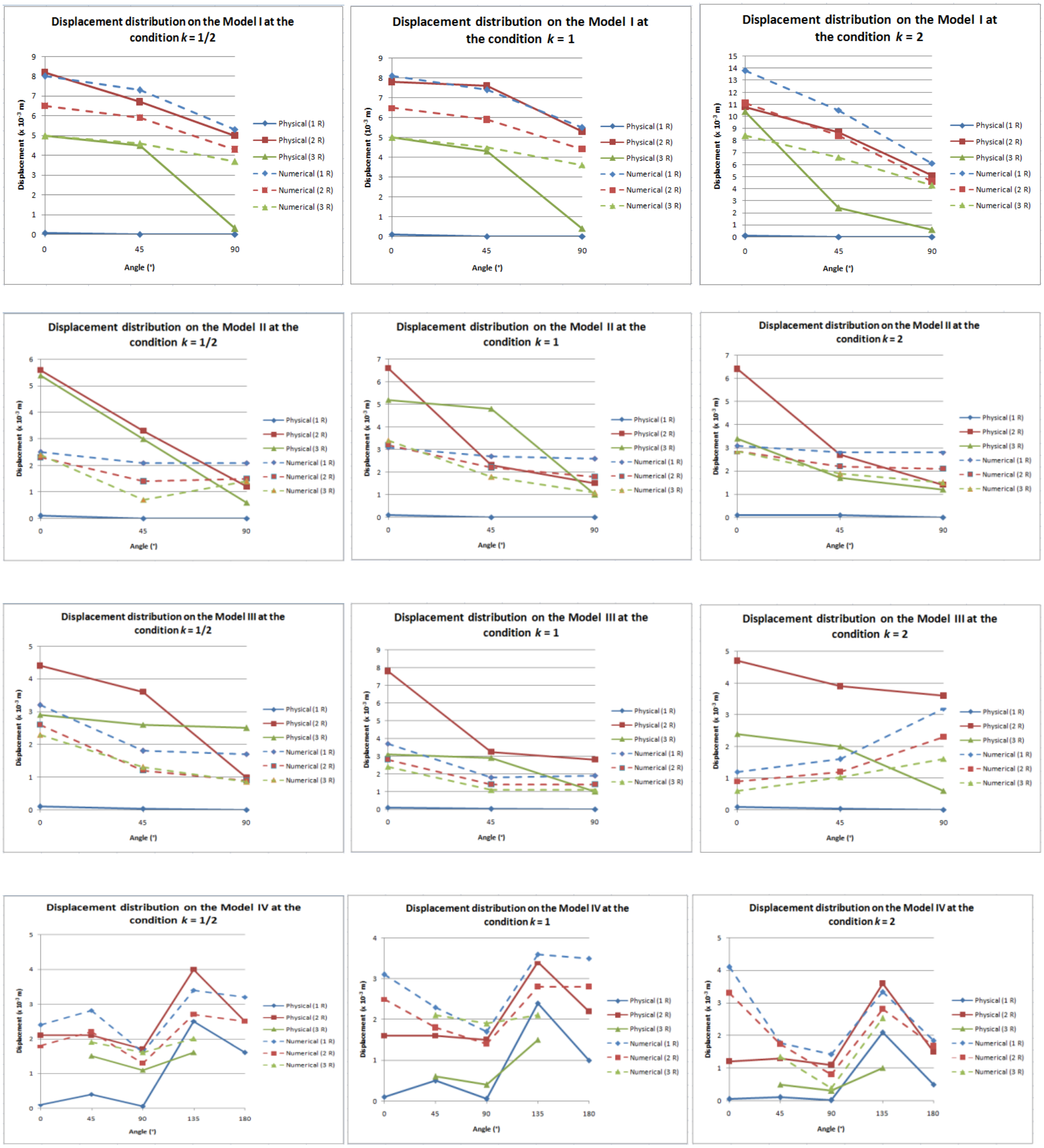

Fig. 3 Displacement distributions in physical and numerical model

4. Numerical Modeling

Biaxial test results on each physical model are back-analyzed numerically by the finite element method. One of the software using the finite element method to solve this problem is *Rocscience 3* (Rocscience).

The purpose of modeling is to provide an overview of the displacement distributions of opening in biaxial loading condition. The results of displacement from numerical modeling would be compared to the results of physical modeling biaxial tests in the laboratory.

Geometry of numerical modeling is made equal to the physical model that was tested in the laboratory with the geometry of 45 cm x 45 cm x 30 cm. The model is reviewed by using the concept of plane strain. Data of material for *Rocscience 3* program are Generalized Hoek-Brown consist of Young's Modulus, Poisson's Ratio, Intact Comp. Strength, mb Parameter (peak), s Parameter (peak), and a Parameter (peak).

The displacement distributions at the points of measurement (called query on numerical modeling in software Rocscience 3 (Rocscience)) were also observed in the testing biaxial physical model, namely measurement at 1R, 2R and 3R, at every angle of 0 °, 45 ° and 90 °, and the angle of 135 ° and 180 ° (specifically in the model IV) for each condition k = 1/2, k = 1 and k = 2.

5. Conclusions and Suggestions

5.1 Conclusions

1. By comparing the displacement of various conditions k, shows that the greatest displacement occurs in the numerical model of opening without discontinuities at the condition of k = 2, which is on the wall opening at 1R distance from the center of the circle opening, the displacement is 13.8 mm. Based on the variation of conditions k, the greatest displacement occurs at the condition of k = 2.
2. Based on the variations of the opening model, the greatest displacement occurs in the numerical model of opening without discontinuities at the condition k = 2, namely on the wall opening at 1R distance from the center of the circle opening, the displacement is 13.8 mm. Then the next greatest displacement is in the physical model of opening with discontinuities dip 90° at the condition k = 1, namely on the wall opening at 2R distance from the center circle opening, the displacement is 7.8 mm.
3. When viewed from a distance measuring point to the circle center openings, the greatest displacement occurs in the numerical model of opening without discontinuities at the condition k = 2, which is on the wall opening at 1R distance from the center of the circle opening, the displacement is 13.8 mm. Then the next greatest displacement occurs in the physical model of opening with discontinuities dip 90° at the condition k = 1, namely on the wall opening at 2R distance from the center circle opening, the displacement is 7.8 mm.
4. The greatest difference between the displacement of physical model and numerical model seen at the model of opening with discontinuities dip 90° at the condition of k = 2, which is on the wall opening, the difference is 77.93%. Overall, the difference between the displacement of physical model and numerical model averagely is 34.67%. This can occur because in the numerical model, the assumption of isotropic, homogeneous and elastic follow the stress – strain linear relationship and the conditions are ideal. While the physical model made from real material, where the relationship of stress - strain might not be linear.

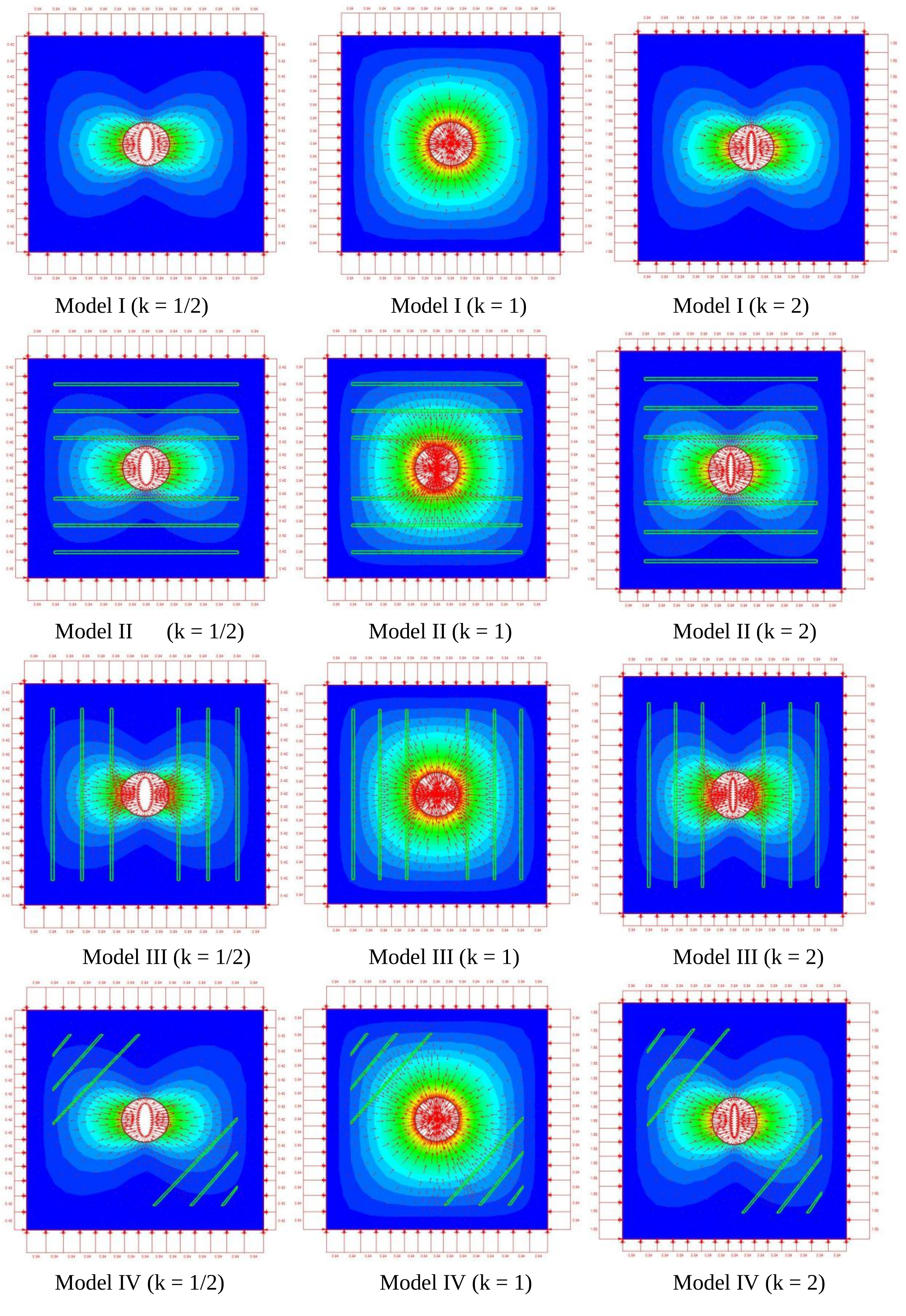

Fig. 4 The displacement vectors in numerical model

5. Physical modeling of openings can be used in studying the distribution of displacement in openings. However, the displacement measuring instrument at 1R distance from the center of the circle openings need to be considered, the measuring instrument should has a good sensitivity so that the displacement can be read. Numerical modeling is used only for data verification of physical modeling. This is because the numerical modeling used an ideal assumption, so back analysis is necessary to be done in the numerical model.

5.2 Suggestions

1. To obtain the measurement results of displacement at 1R more accurate, preferably measuring instrument that can be used has a higher sensitivity (scale per 1 micrometer). In example, using Extensometer tools created in the laboratory, then the tool is inserted into the physical model openings.
2. Sand which is a physical model-forming material composition should be screened beforehand in order to produce a uniform grain of sand to prevent gradation granular material during the creation of a physical model.
3. The dimensions of the physical model is made thicker in order to reach the plane strain condition.

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