Basement rock structure and seepage analysis influences on dam foundation design: Khlong Kra Sae Project area, Bo Thong district, Chonburi province, Thailand.

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Abstract

Basement rock structure and seepage analysis of dam foundation are important in dam design, geological field investigation and hydrogeology field investigation should be studied in detail. In this paper, rock structural characterization of rock masses used for evaluate discontinuity pattern compared to seepage analysis of dam foundation by using finite element method (FEM) in anisotropy seepage focus on basement rock. The eastern part of Thailand is defined to be tectonic zone that compose of fold and thrust belts which is product from the Indosinian orogeny during the Permian–Triassic Period. The structural analysis and synthesis was constructed the idealize modeling of rock structure in study area. In project area composed of Triassic sandstone. Rock structure analysis in Kholng Kra Sae Project illustrate bedding in E–W and NE–SW trend dip direction to south. Structure synthesis of bedding in **π**–diagram show overturn fold. Folding has axial plane orientate about 071°/54°SE. Joint patterns are illustrating dip directions to 4 directions which composed of SW, NW, NE and SE. In addition, joint pattern shows sub-perpendicular trend, that indicates blocky or net pattern. Results from numerical modeling are corresponding to geological investigation, it was showed that discontinuity pattern causes an affect to horizontal discontinuity is continuous more than vertical discontinuity, that causes to water can flow in horizontal easier than vertical flow. Therefore, sensitivity analysis of anisotropic permeability, it was founded that variable ratio in horizontal permeability flow are significantly to considerer more than vertical permeability.

Keywords: Structural analysis and synthesis, structural Idealize modelling, Tectonic, seepage analysis, finite element method, steady state flow.

1. Introduction

The tectonic events in the past constructed feature of rock structure in eastern part of Thailand. Rock structure study in Khlong Kra Sae Project area for support in dam detail design. Structural geology of this study focuses in rock structure and discontinuity such as bedding, jointing, fracturing, faulting and folding. These structural data can be used for analysis and synthesis. Synthesis data process constructs idealized modeling in study area. Seepage analysis of dams is also one of the major interesting point in geological and geotechnical engineering. The amount of seeping water through and under dam together with the distribution of the water pressure can be estimated by using the theory of flow through porous media and using the finite element to solve the governing equations of flow through dams and foundation (Fattah, 2014). Geological features and ground condition of dam site greatly affect in amount of seepage and relevant effect. (Turkman, 2003) Geological and hydrogeological on surface and subsurface investigation are important. Numerical method has been applied to carry out seepage analysis in a permeable medium. However, they are all developed for a continuous medium and not suitable for a highly fractured rock mass since the important geological and hydraulic features of fractures cannot be considered explicitly in the seepage analysis (Ren, 2016). Seepage flow through an earth fill dam was simulated, three sets of steady state numerical modeling were presented. Two sets of parametric studies on long-term steady state flow were conducted using homogeneous and zoned earthfill dams for studying the behavior of seepage in the dams. (Kasim and Fei 2002). SEEP2D was used to determine the free surface seepage line, the quantity of seepage through Duhok dam, the total head measurements and the effect of anisotropy of the core materials of Duhok dam. The effect of the ratio of the permeability in the horizontal direction to that in the vertical direction (K_x/K_y) on seepage was tested and the results indicated an increase in seepage quantity as this ratio increased. (Noori and Ismaeel 2009). Purpose of this study is evaluate discontinuity pattern comparing with seepage analysis of dam foundation by FEM in anisotropy.

2. Geological investigation

Khong Kra Sae Project located in Bo Thong Sub-district, Chonburi Province. The study area located at latitude 13°11'27.29" north and longitude 101°35'57.03"(Fig.1) Geomorphology of the study area illustrates dome and basin. Canal width is 5-10 meters. Slope of the left abutment and right abutment are about 1:25 and 1:50 respectively. Thickness of overburden in center line of dam rank between 2.35 – 6.00 meters. Soil composed of silty sand (SM) and clayey sand (SC)

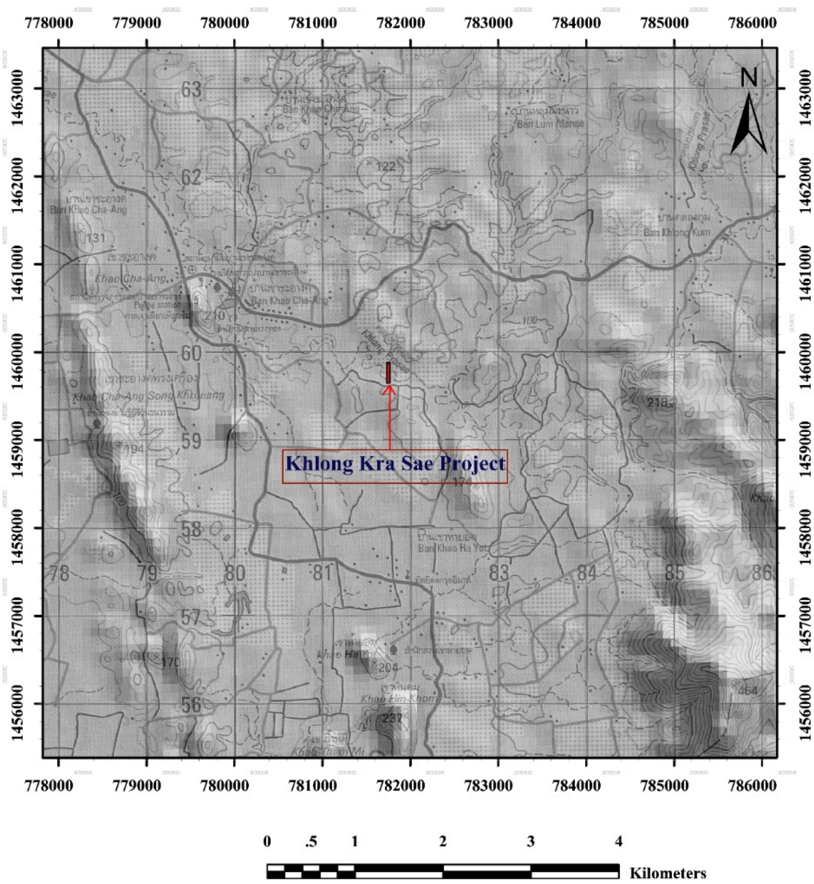

Fig.1 Location of Kra Sae Project (after RTSD, 1999)

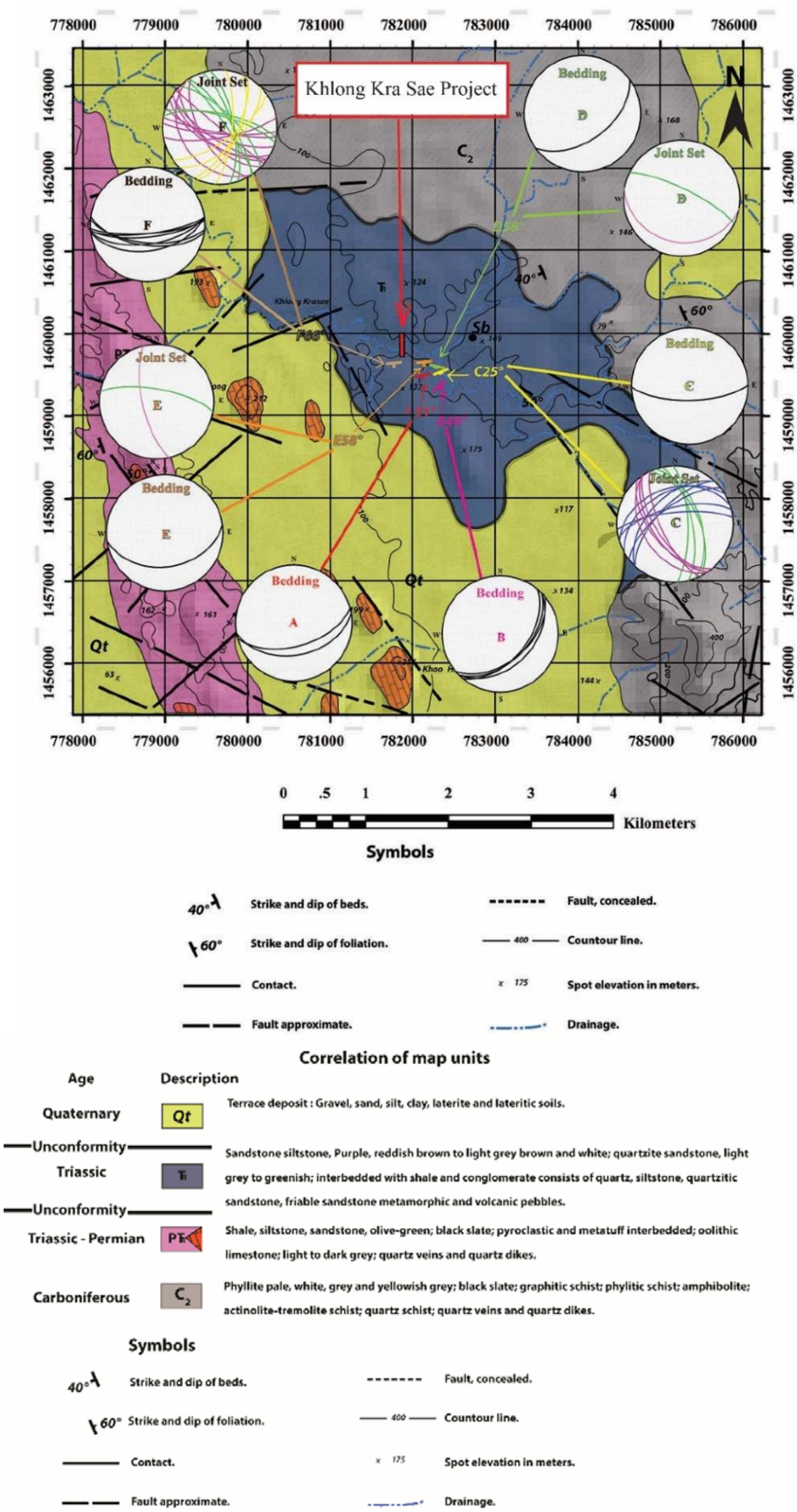

Fig. 2 Illustrate geological map in scale 1: 50,000 and outcrop in dam reservoir (after Kittisarn and Assavapatchara, 1988)

Geological mapping scale 1: 50,000 of department of mineral resources can be recognized rocks to 4 group by geological time. (Kittisarn and Assavapatchara, 1988). Stratigraphy of rock group (Fig.2) from older to younger consist of Carboniferous group, Triassic-Permian group, Permian group, Triassic group and Quaternary group. Khlong Kra Sae Project located on Triassic group. Regional of rock structure show bedding trend in NW-SE direction and dip to SW about 40°. Moreover, the strike-slip fault present in the geological map.

The influence of tectonic in eastern part of Thailand can be recognized to 2 scenarios of tectonic event. The first movement event is from Indosinian orogeny during Triassic. The Indosinian orogeny cause Sibumasu plate cashed to Indochina plate (Booth and Sattayarak, 2011). This event generates trend of rock basement in eastern of Thailand about N-S, NW-SE to E-W trend of fold belt and suture. These trends be constructed from Sibumasu plate collided with Indochina plate. (Bunopas, 1981; Bunopas et al., 2001; Metcalfe, 2002; Metcalfe, 2011; Metcalfe, 2013).The second scenario from Cenozoic. This event generated trend of structure in NW-SE direction. These trends were constructed from India-Australia plate crashed Eurasia plate. (Kanjanapayont et al., 2013; Morley, 2002; Morley, 2007; Morley, 2012; Morley et al., 2013; Morley and Charoentitirat, 2011; Palin et al., 2013; Pubellier and Morley, 2014; Ridd, 2012; Ridd and Morley, 2011; Tapponnier, 1986).

Structure of rock basement in Khlong Kra Sae Project have impact from tectonic event. The Triassic rock unit in Khlong Kra Sae Project illustrate strike of bedding in NW-SE with dip 40° dip direction to SW. Outcrop in reservoir area was found in 6 stations (Fig.2).

Station A (Fig. 3A) outcrop is coarse to fine-grained sandstone and is far from centerline of dam in SE direction about 280 meters. This station measure bedding plane that is 075°/57° SE and 080°/44°SE

Station B (Fig. 3B) outcrop is coarse to fine-grained sandstone and is far from centerline of dam in SE direction about 520 meters. Sandstone show bedding 075°/57°SE and 080°/44°SE

Station C (Fig. 3C) outcrop is medium to fine-grained sandstone show slip plane approximately 6 centimeters and far from centerline of dam in SE direction about 370 meters. Sandstone present bedding trend NE-SW dip direction to SE direction.

Station D (Fig. 3D) outcrop is coarse to fine-grained sandstone and is far from centerline of dam in SE direction about 370 meters. Sandstone illustrate pure shear in NW-SE compression. This compression generated plan about 247°/55°NW and 255°/38°NW (green plane in Fig. 3D). While, simple shear was occurred 2 times, the first-time generated slip plane within green plane distance approximately 5 centimeters and the second-time constructed slip plane within violet plane distance approximately 6 centimeters. Overall of simple shear move in clockwise movement.

Station E (Fig. 3E) outcrop is coarse to fine-grained sandstone and is far from centerline of dam in S direction about 180 meters. Bedding $100^{\circ}/25^{\circ}$SW and $296^{\circ}/77^{\circ}$NE.

Station F (Fig. 3F) outcrop is coarse to fine-grained sandstone and is far from center line of dam in SW direction about 305 meters. Bedding $280^{\circ}/72^{\circ}$NE and $167^{\circ}/70^{\circ}$SW.

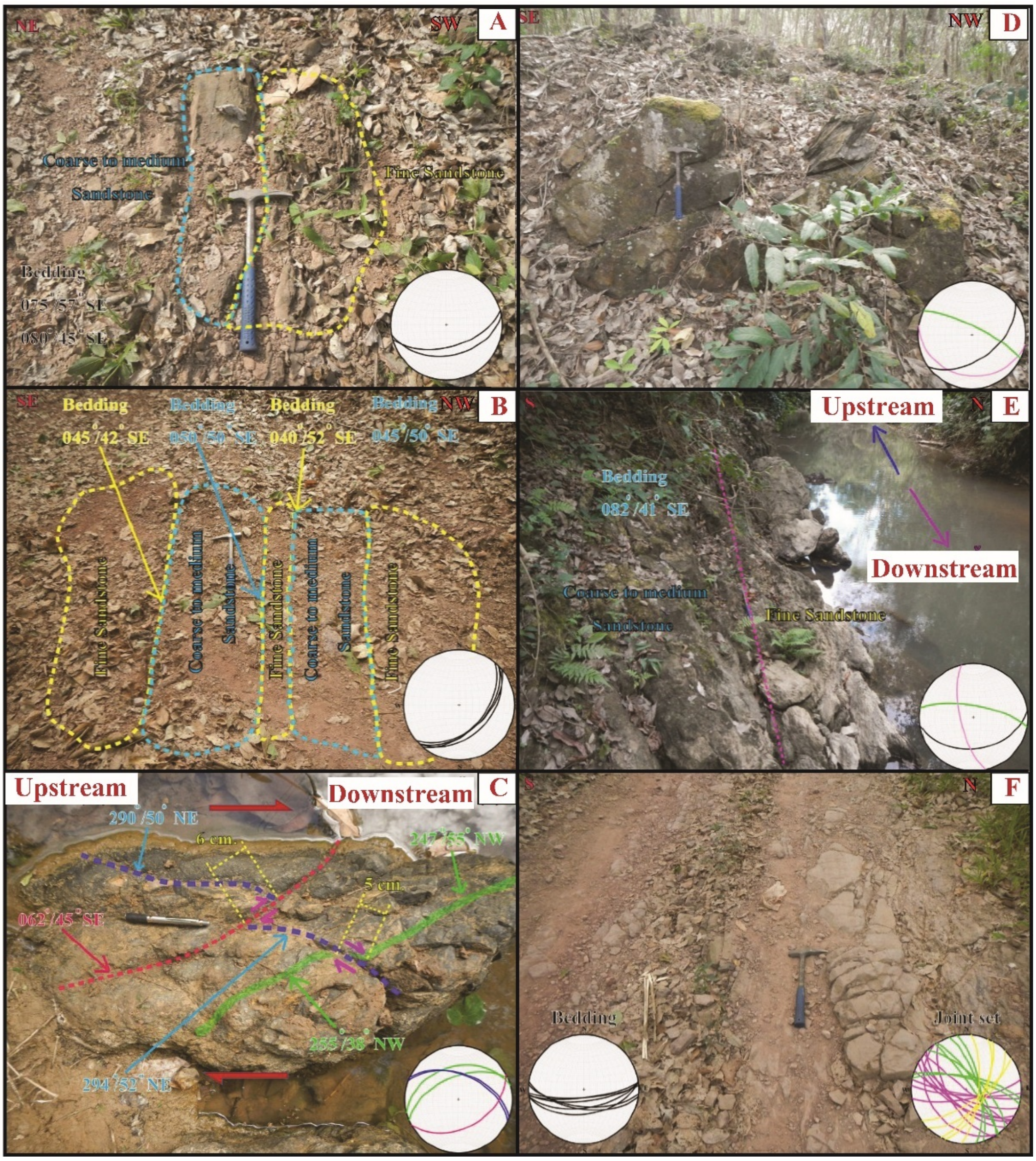

Fig.3 Show outcrops in 6 stations; (A) Station 1 is coarse to fine-grained sandstone, (B) Station 2 is coarse to fine-grained sandstone, (C) Station 3 is slip plane in fine-grained sandstone in Khlong Kra Sae Area, (D) Station 4 outcrop is coarse to fine-

grained sandstone, (E) Station 5 outcrop is coarse to fine-grained sandstone, (F) station 6 outcrops is coarse to fine-grained sandstone.

Exploration 6 stations in reservoir area show bedding into 2 trends which compose of

1) Bedding strike trend NE-SW direction are 075°/57°SE, 080°/44°SE, 045°/42° SE and 050°/50°SE

2) Bedding strike trend almost E-W 098°/60°SW and 095°/64°SW.

From example of bedding in project area designate that beddings have trend in NE-SW and almost E-W directions. In eastern of Thailand and joint pattern illustrates 4 dip directions which compose of SW, NW, NE and SE.

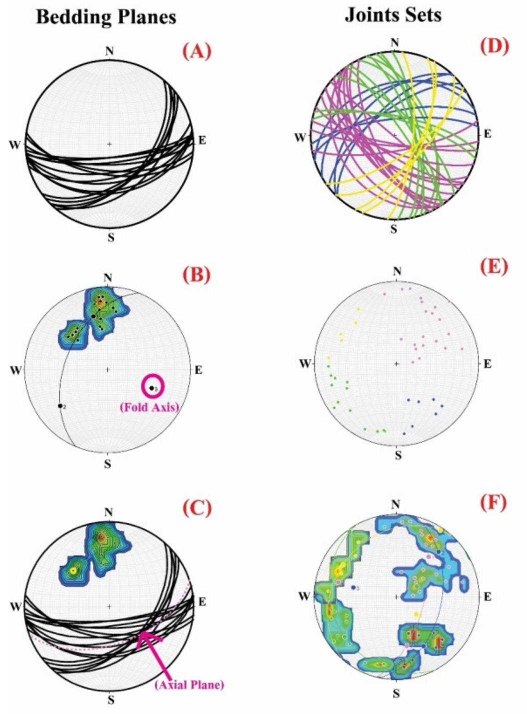

Fig.4 Structural analysis of bedding planes and joint pattern. (A) Stereonet plot of bedding planes. (B) π-diagram plot pole of bedding. (C) Contour plot pole of bedding and bedding plane. (D) Stereonet plot plane of joint patterns yellow lines dip direction to SE, green lines dip direction to NE, pink lines dip direction to SW and blue lines dip direction to NW. (E) Dispersion pole plot of joint set. (F) Dispersion of joint pattern plot.

3. Structural analysis and synthesis methods

Rock bedding was analyzed on stereonet diagram by plane plot. Bedding plane is recognized into 2 trends, NW-SE and almost E-W trend (Fig.4A). Plotting pole of plane (Fig. 4B) show bedding plane 2 trend indicate in study area has folding structure. Contour plot from pole (Fig.4C) axial plane and feature of folding also in joint pattern plot plane (Fig. 4D) separated to 4 patterns. Each pattern has dip direction of joints pattern and plot poles of joints (Fig. 4E). Joint pattern separates in 4 dip direction (Fig. 4F).

Data from structural analysis can be synthesis idealized modeling in interpretation tectonic force action to basement rock in Klong Kra Sae Project. Structural evolution be recognized up to 3 scenarios. The first scenario was beginning deposition sediment and compaction to be sandstone (Fig. 5A) with tectonic force direction about south verging to north (green plane in Fig.3c). The second scenario is these force (pure shear) generated fold structure (Fig. 5B) from plate tectonic collision. Third scenario, simple shear rotation in clockwise movement (Fig. 5C) constructed rock basement structure (Fig.5D). The center line of dam in Khlong Kra Sae Project construct perpendicular with bedding planes and slip planes (Fig. 5E).

Rock basement have tendency to seepage in foundation. Because, firstly bedding planes are perpendicular with center line of dam is a potential and slip plane was found in Khlong Kra Sae, there is an opportunity to come up.

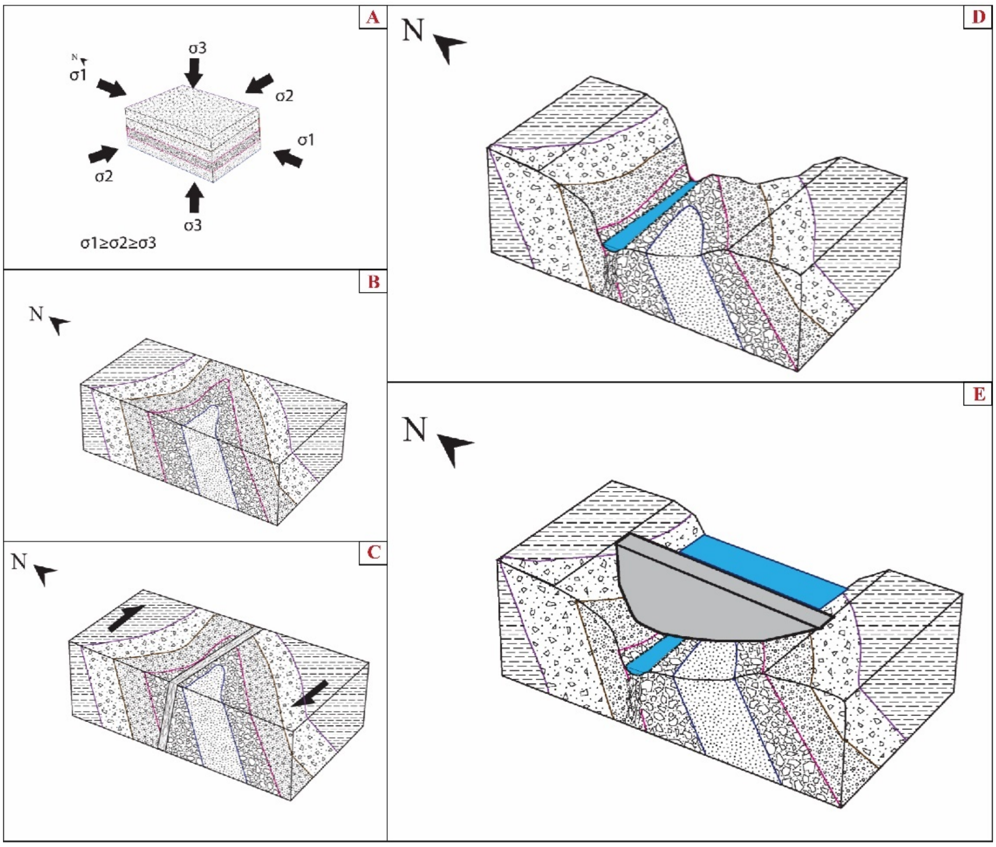

Fig.5 Illustrate synthesis of structural evolution in Khlong Kra Sae project area. (A) influence of pure shear to Triassic sediments. (B) Folding from pure shear. (C) Simple shear clockwise movement. (D) Idealized structure modeling in Khlong Kra Sae project. (E) Center line of dam perpendicular with bedding planes and slip planes.

4. Hydrogeological investigation

Permeability is defined the seepage flow through interconnecting void, the resistance to flow depends upon type of rock, size and shape of the voids, and surface tension of water. Seepage flow through intact rock is negligible ($K_{Primary}$) and essentially all flow occurs along the discontinuity ($K_{seoondary}$) (Wyllie & Mah, 2004).

Darcy's law is applicable to porous media and so can be used to studied water flow in both intact rock and rock mass in term of laminar flow. However, Darcy's law is not applicable in non–linear or turbulent flow in and individual fracture. Double porosity considers seepage flow in both fractured or discontinuity network and rock matrix. Discontinuity orientation, aperture, set number and distribution are significantly in fracture rock mass (Ren, 2016)

From Darcy's law velocity (v) in x, y and z direction in steady state seepage flow has given by

$$Kx\frac{\partial^2 h}{\partial x^2}+Ky\frac{\partial^2 h}{\partial y^2}+Kz\frac{\partial^2 h}{\partial z^2}=0 \quad (1)$$

In case of isotropic permeability (K_x = K_y = K_z) can wrote to lapace equation has given by

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}+\frac{\partial^2 h}{\partial z^2}=0$$

(2)

Nevertheless, in case of anisotropic permeability ($K_x \neq K_y \neq K_z$) has given by

$$\frac{\partial^2 h}{\partial {x_t}^2}+\frac{\partial^2 h}{\partial {y_t}^2}+\frac{\partial^2 h}{\partial {z_t}^2}=0 \quad (3)$$

where: $x_t = \frac{x}{\sqrt{k_x}}$, $y_t = \frac{y}{\sqrt{k_y}}$, $x_t = \frac{x}{\sqrt{k_x}}$,

Flow in clean and smooth discontinuities, water flow through rock mass has been studied by Huitt (1956), Snow (1965), Sharp (1970), Maini (1971) and other. However, to determine seepage water through rock mass in laminar flow smooth and clean discontinuity (Dans,1969) the relationship with permeability and discontinuity spacing and separation has given by

$$K = \frac{ge^2}{12vb} \quad (4)$$

where: g is gravitational acceleration, e and b are discontinuity aperture and spacing, and v is the coefficient of kinematic viscosity ($1.01E^{-06}$ m^2/s)

Flow in filled discontinuities, Laminar seepage flow through parallel discontinuities with in filled materials, (Louis,1976) it is show that the hydraulic conductivity is lowest than equation (1) and given by

$$\mathrm{K} = \frac{e}{b}Kf + Kr \quad (5)$$

where: Kf is the hydraulic conductivity of filling and Kr is that of in tock rock.

Lugeon method or water pressure test developed by Lugeon (1933) is based on the luqeon unit, one luqeon unit mean one liter of water absorption at rate of 1 liter / 1 meter in 1 minute at 10 bars. This test does not give hydraulic conductivity. However, that gives a quantitative comparison of the in-situ permeability. Generally speaking, if has high lugeon value it will have more discontinuities with high permeability of dam foundation. Lugeon value have given by

$$\mathrm{Lu} = \frac{10Q}{LP} \tag{6}$$

where: Lu is lugeon value, Q is flow rate, P is pressure (testing) and L is length (testing)

Lugeon value was consider from comprehensive pressure test to classification of water flow pattern through rock mass, can be device to 5 characteristics as laminar, turbulent, dilation, wash out and void filling. (Houslby 1992)

Standard Lugeon tests give average and isotropic K permeability values which strictly refer to the rock volume surrounding the length of borehole where the test is performed. In fractured rock mass where hydraulic conductivity is controlled by discontinuities, Lugeon K values are not representative of the real permeability of rock mass and not extensible to large volumes of rock. Therefore, we carried out a new methodology for evaluating the permeability should be based on a survey of the geostructural properties of the rock mass and through Lugeon tests, in fact, it is possible to evaluate a mean permeability coefficient (K_m) for the length of the boreholes where tests were performed. This coefficient is susceptible to the presence of structural features like wide opening fissures in rock masses and it has no orientation in the space. (Coli, 2008)

Foundation seepage flow through dam when it began to contain water. Upstream water level is higher than downstream water can flow through dam and foundation from upstream to downstream. In case of rock foundation seepage flow are in discontinuity of rock in anisotropic and heterogeneous are control flow behavior and flow velocity depending upon aperture and spacing. Discrete model and Homogeneous model was classified into seepage flow model by Theil (1989) and Wittke (1990)

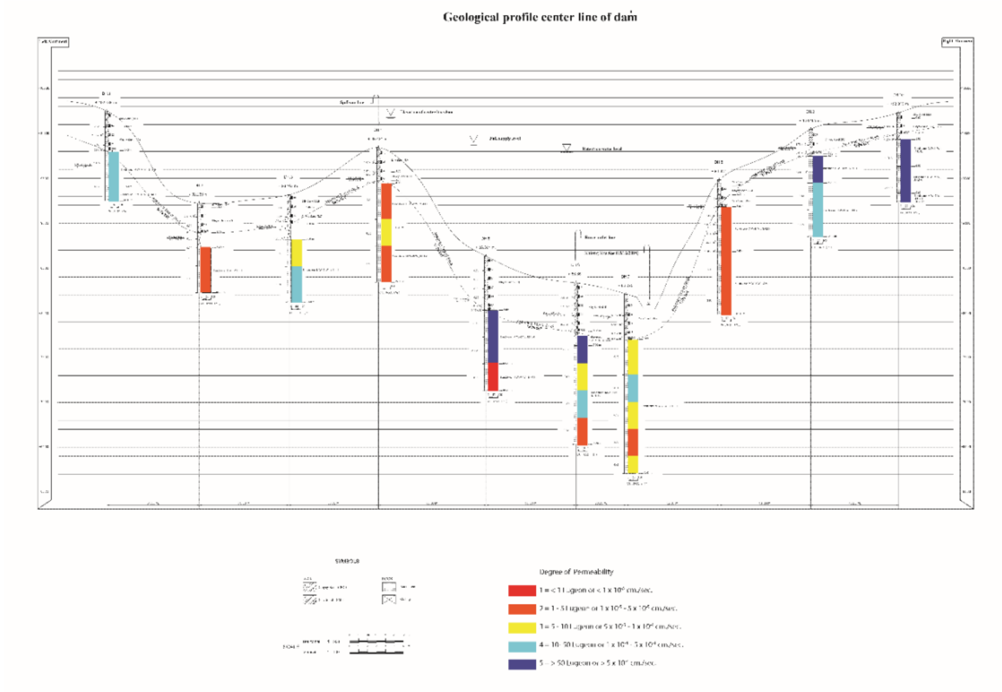

Fig. 6 Lugeon test value along center line of dam. The result showed that lugeon is high value (Over 50 lugeon) at right abutment and Khong Kra Sae riverbank lugeon value are quite high (That results vary to 1-50 lugeon)

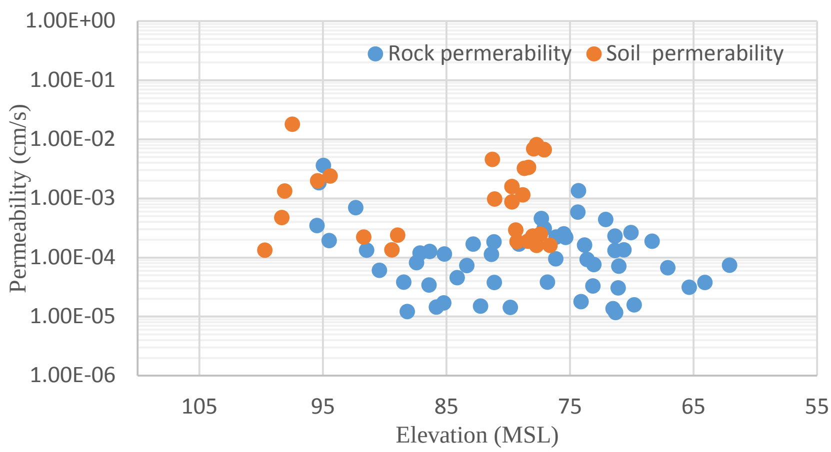

Fig. 7 Foundation (soil and rock) permeability results from lugeon and open-end test (Lugeon value gives quantitative comparison to permeability, thus 1 lugeon equal to 1.30E^{-05} cm/sec or approximately to 1.00E^{-05} cm/sec)

Lugeon value has been quantitative compare to permeability value (Fig.7). The results were evaluated parameter for seepage analysis of dam foundation, thus foundation 1 and 2 saturated permeability equal to 1.00E^{-04} and 1.00E^{-05} (m/sec) respectively. However, parameter of core zone and random zone were collected from laboratory testing, the results gave saturated permeability equal to 1.00E^{-07} (m/sec)` for core zone and 1.00E$^{-05}$ (m/sec)` for random zone (Table 1).

5. Finite element seepage analysis

Seepage analysis of basement rock structure Khlong Kra Sae dam project is analyzed by finite element method. SEEP/W (GEO-SLOPE, 1999) was used to model water pressure of soil and rock foundations in saturate and unsaturated condition with steady state flow, in case of anisotropic permeability base on equation (3)

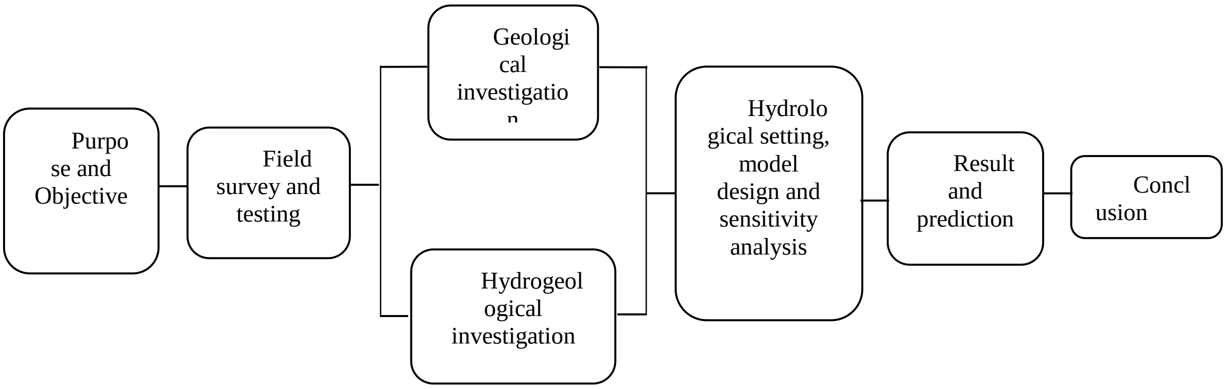

Fig. 8 Illustrates scheme of workflow.

In this model were simulated to 3 cases. Case I (table 1) at full supply level (FWL), case II (table 2) at retention water level (RWL) and case III (table 3) at minimum water level (MWL) focuses on anisotropy permeability.

The effect of the ratio of the permeability in the horizontal direction to that in the vertical direction (K_x/K_y) on seepage analysis was tested with various anisotropic permeability ratio to 0.1, 0.2, 0.5, 1.0, 2.0, 5.0 and 10.0 to seepage model (table 2-4).

Table 1 Materials properties assumed for modeling.

Materials	Model	K_{Sat} (m/sec)
Foundation 1	Saturated Only	$1.00E^{-04}$
Foundation 2	Saturated Only	$1.00E^{-05}$
Core Zone	Saturated / Unsaturated	$1.00E^{-07}$
Random Zone	Saturated / Unsaturated	$1.00E^{-05}$

Table 2 Results of flux value in various ratio in case of full supply level (FWL).

Ratio	Q_{total} (m^3/sec)	Q_d (m^3/sec)	Q_f (m^3/sec)
0.10	$3.14E^{-04}$	$2.9513E^{-06}$	$3.1086E^{-04}$
0.20	$3.39E^{-04}$	$2.9272E^{-06}$	$3.3596E^{-04}$
0.50	$3.62E^{-04}$	$2.9092E^{-06}$	$3.5862E^{-04}$
1.00	$3.72E^{-04}$	$2.9030E^{-06}$	$3.6949E^{-04}$
2.00	$3.79E^{-04}$	$2.8996E^{-06}$	$3.7644E^{-04}$
5.00	$3.85E^{-04}$	$2.8986E^{-06}$	$3.8166E^{-04}$
10.00	$3.87E^{-04}$	$2.8988E^{-06}$	$3.8391E^{-04}$

Table 3 Results of flux value in various ratio in case of retention water level (RWL).

Ratio	Q_{total} (m^3/sec)	Q_d (m^3/sec)	Q_f (m^3/sec)
0.10	$2.96E^{-04}$	$1.93E^{-06}$	$2.94E^{-04}$
0.20	$3.17E^{-04}$	$1.91E^{-06}$	$3.15E^{-04}$
0.50	$3.38E^{-04}$	$1.89E\text{-}^{06}$	$3.36E^{-04}$
1.00	$3.49E^{-04}$	$1.85E^{-06}$	$3.47E^{-04}$
2.00	$3.56E^{-04}$	$1.88E^{-06}$	$3.54E^{-04}$
5.00	$3.60E^{-04}$	$1.88E^{-06}$	$3.58E^{-04}$
10.00	$3.62E\text{-}^{04}$	$1.81E^{-06}$	$3.60E^{-04}$

Table 4 Results of flux value in various ratio in case of minimum water level (MWL).

Ratio	Q_{total} (m^3/sec)	Q_d (m^3/sec)	Q_f (m^3/sec)
0.10	$1.17E^{-04}$	$1.71E^{-07}$	$1.17E^{-04}$
0.20	$1.27E^{-04}$	$1.23E^{-07}$	$1.27E^{-04}$
0.50	$1.36E^{-04}$	$1.09E^{-07}$	$1.36E^{-04}$
1.00	$1.41E^{-04}$	$1.07E^{-07}$	$1.41E^{-04}$
2.00	$1.44E^{-04}$	$1.06E^{-07}$	$1.44E^{-04}$
5.00	$1.46E^{-04}$	$1.06E^{-07}$	$1.46E^{-04}$
10.00	$1.47E^{-04}$	$1.05E^{-07}$	$1.47E^{-04}$

6. Discussion

Khlong Kra Sae illustrated beddings of rock into two trends. Strike of bedding show NE-SW almost E-W and directions dip to south. Beddings have thickness between 5 cm up to 100 cm. Synthesis rock basement structure show rock folding.

Folding is overturn fold. Axial plane orientates about 071°/54° SE. Joint patterns are illustrates dip directions to 4 directions which composed of SW, NW, NE and SE.

It is showed that beds and joints are illustrates rock mass to blocky or net pattern, discontinuity spacing around 3 cm up to 30 cm.

SEEP/W numerical modeling showed flux value, flow direction and cross section in deep section across dam body (Fig.10). Flux value though dam body does not show significance when vary anisotropic permeability ratios (Fig.9B). However, flux value though dam foundation in case of horizontal permeability flow (K_x) more than vertical permeability flow (K_y), it was found that seepage flow value decreased when increased K_x (Fig.9A and 9B). Flux value very changeable when vary anisotropic permeability ratio as 0.1, 0.2 and 0.5 to compared with isotropic permeability as 15%, 9% and 3% respectively (Fig.9D). Nevertheless, foundation in case of horizontal permeability flow (K_x) less than vertical permeability flow (K_y) was not significance to changeable with isotropic permeability, (Fig.9D).

Results from numerical modeling are corresponding to geological investigation, it was showed that strike of bedding are perpendicular with center line of dam and joints are cutting into the rock mass and illustrates rock mass to blocky. That's discontinuity pattern causes an affect to horizontal discontinuity is continuous more than vertical discontinuity, that causes to water can flow in horizontal easier than vertical flow. Therefore, sensitivity analysis of anisotropic permeability, it was founded that variable ratios in horizontal permeability flow are significantly to consider more than vertical permeability.

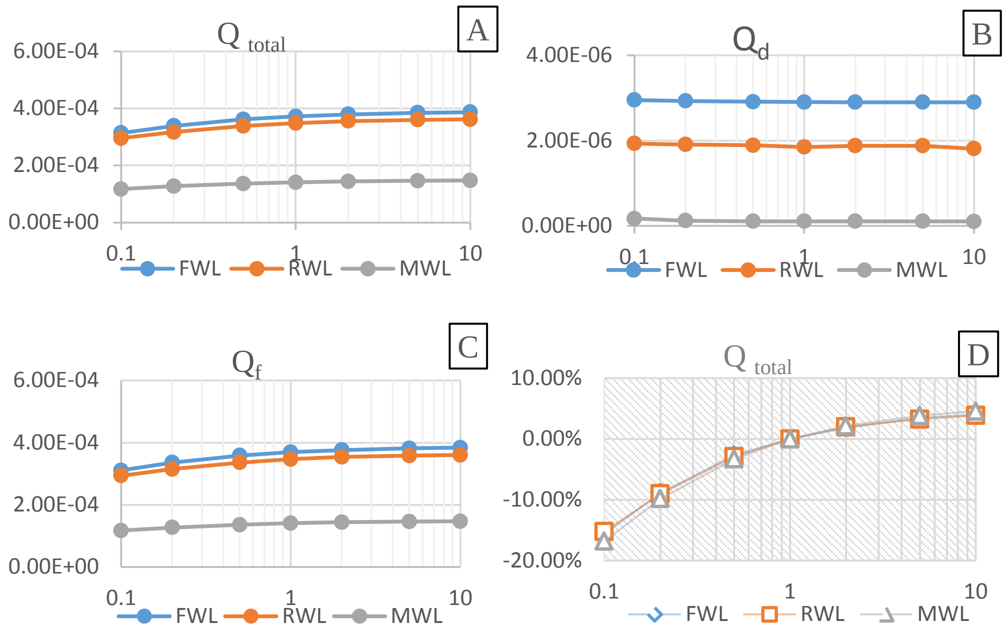

Fig. 9 Distribution of flux value m^3/sec (y axis) and various ratio (x-axis) on figure 9A-9C in term of water flow through dam (Q_d), water flow through foundation (Q_f) and total water flow (Q_{total}). Percentage of flux value change in various ratio compare with isotropy permeability (y axis) and various ratio (x-axis) illustrated on figure 9D

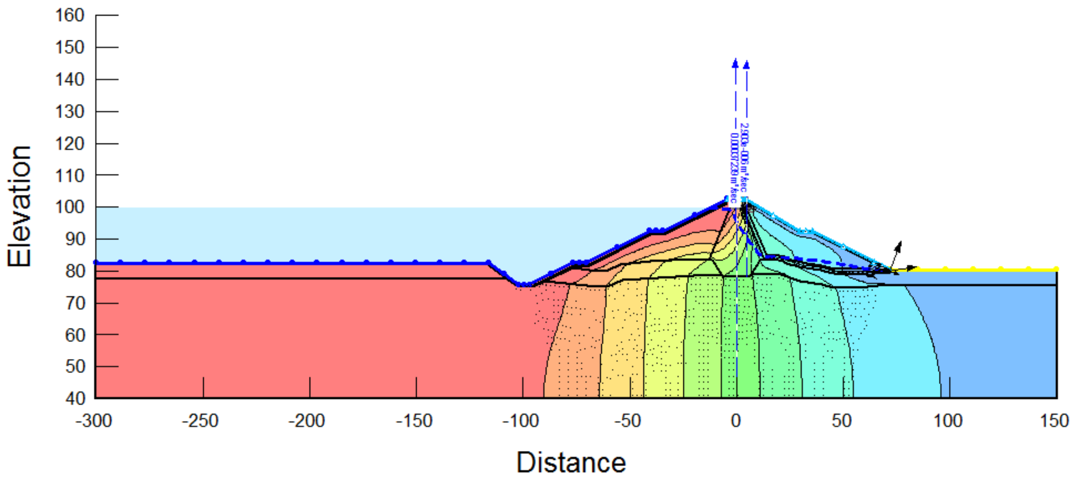

Fig. 10 Finite elements seepage analysis of total head and flux value in case of HWL, permeability ratio equal to 1

7. Conclusion

Structural geology of basement rock such as faults, folds, bedding and joints were studied to interprete rock mass characterictic and discontinuity pattern, for estimated seepage flow assumption. Hydrogeological investigation such as field permeability test or open end test and lugeon test were collect that data to assumed parameter for numerical model. SEEP/W was used to analyze seepage flow with 3 cases such as FWL, RWL and MWL, anisotropic permeability ratio (K_y/K_x) used to analysis flow charateristic of horizontal and vertical flow. In that results horizontal permeability are sensitivity more than vertical permeability. It was concluded that geological studied on highly fractured rock mass since geological and hydraulic features of fractures should be considered explicitly in the seepage analysis.

Geological and hydrogeological investigation are improtant for geotechnical and geological engineering. This study to helps engineering to gained more understanding of seepage on fracture rock and anisotropic permeability of rock.

Nevertheless, to determination of permeability in fracture rock is very difficult for complex geological conditions, because the water flow into the rock mass is controlled by the discontinuity network, therefore permeability is high anisotropic and it changes with the variation of discontinuity properties and the geological structure of the formation.

Future study should be study in more detail on seepage though discontinuity orientation, hence it cause affect to permeability, new asumsion boundary condision and sensitivity test shold be examine. Permeability tensor, pipe network model for seepage analysis of seepage fracture rock and discrete element method should be consider for seepage analysis of dam foundation.

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