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DETERMINATION OF NUCLEAR POWER PLANT SITE IN WEST BANGKA BASED ON ROCK MASS RATING AND GEOLOGICAL STRENGTH INDEX

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Abstract

Indonesian government through the National Atomic Energy Agency has planned to build a nuclear power plant. One of the proposed sites is in West Bangka Regency, Bangka Belitung Archipelago Province. The engineering geology of this area is, however, not fully understood and requires further investigations. Engineering geology investigations were carried out by assessing the rock mass quality and bearing capacity based on field observation and drilling data. The assessment was conducted using Rock Mass Rating (RMR) and Geological Strength Index (GSI) classification. The rock mass in the study area was divided into four units, namely Units of Sandstone, Granite, Mudstone and Pebbly Sandstone. The RMR and GSI values in the study area are influenced by the parameters of discontinuity space density, the slope of discontinuity orientation, grade of weathering and groundwater conditions. The assessment shows that the Granite Unit has the best quality which is shown by the average RMR value of 53 and GSI value of 66. Based on the average RMR value, the Granite Unit is estimated to have cohesion value between 0.2 and 0.3 MPa, friction angle between 25° and 35°, and allowable bearing pressure between 280 and 135 T/m^2. Based on the GSI value, the Granite Unit is estimated to have uniaxial compressive strength value between 1.0465 and 183.8 MPa, tensile strength between (-0.0122) and (-5.2625) MPa, rock mass strength values between 24.5244 and 220.351 MPa, and modulus of deformation within a range of 1.73–86.68 GPa. The Granite Unit is considered to be the most appropriate location for the nuclear power plants.

Keywords: *Nuclear power plant foundation, geological strength index, rock mass rating, rock mass quality*

1 Introduction

Construction of Nuclear Power Plant is a way to overcome the limitations of electrical energy in Indonesia. The feasibility study of nuclear power plant site is done in Muntok District, West Bangka Regency, Bangka Belitung Archipelago Province (Figure 1). The investigation was conducted in a comprehensive manner, including the engineering geology condition of rock.

Bangka Island is located in the Sunda Shelf (Van Bemmelen, 1970), at the Sundaland Craton (Barber *et al.*, 2005). Sunda Shelf is a combination of some terrane that amalgamated with Asia (Van Gorsel, 2012). The regional geological conditions show Complex Pemali rocks formed at the Perm time as the oldest rocks, and then deposited Tanjung Genting Formation rocks on Early Triassic, further on Late Triassic – Late Jurrasic occurred Granite Klabat in-

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trusion, and then as unconformity deposited Ranggam Formation at Late Miocene – Early Pleistocene (Margono, *et al.*, 1995; Mangga and Djamal, 1995).

Wyllie and Mah (2004) and Giani (1992) states rock material experienced a collapse as the rock mass. Rocks mass is constructed by blocks of rock and discontinuities as a union (Palstrom, 1995). Each type of rock has different character and mechanics ability (Goodman, 1989). Rock mechanics analysis requires a model and geological data based on rock type, discontinuities structure and material properties (Hoek, 2007). Geological data collection stages are reference study, Reconnaissance, drilling exploration, trenching and pitting, in situ testing, detail testing and mapping (Cheng and Lau, 2008). As for a comprehensive investigation of the discontinuities has been advanced by Wyllie (1999).

The study aims to evaluate the rock mass quality for estimating the bearing capacity and determine the best location of the shallow foundation of a nuclear power plant. Rock Mass Rating (RMR) (Bieniawski, 1989) and the Geological Strength Index (GSI) Classifications (Hoek, 1994) is used in estimating the quality and bearing capacity of rock mass for a raft foundation of the nuclear power plants.

2 Research methods

The study was conducted throughout the Rock Mass Rating (RMR) (Bieniawski, 1989) and the Geological Strength Index (GSI) Methods Hoek (1994), using outcrop and core bore data. Rock Strength (UCS) obtained from rebound values conversion of digital Schmidt hammer type N using Kilic and Teymen (2008) equation, while the adjustment value of discontinuity orientation on RMR classification using IS 12070 standard (1987). Based on RMR rock value can be estimated the values of cohesion and internal friction angle, likewise allowable bearing pressure is estimated by Mehrota (2011) scheme. The rock mass strength and modulus of deformation is calculated using GSI Method (Hoek *et al.*, 2002).

3 Results and discussion

Detailed geological conditions of study area have been described by Irvani *et al.* (2013) and Irvani (2013). Geomorphological units were developed is Flat, Gently Sloping, Sloping, and Moderately Steep Hill Geomorphology Units. The lithologies from the youngest to the oldest are Triassic Sandstone, Late Triassic – Jurasic Granite, Late Miocene – Pleistocene Mudstone and Pebbly Sandstone.

Diskontinuity orientation

Stereographic analysis using a Dips v.5.1 software that applied to the discontinuities orientation for every rock unit (Figure 2), except Pebbly Sandstone Unit, showed that Rose Diagram for Sandstone Unit have a major northwest-southeast orientation (N 305°E) and northeast-southwest (N 25°E), Granite Unit have a principle north-south orientation (N 05°E) and northwest-southeast (N 305°E), whereas for the Mudstone Unit oriented is north-south (N 05°E) and east-west (N 275°E). In general, direction of the relative orientation of the discontinuities all rock units are northwest-southeast and north-south. The estimation faults in the study area is old inactive faults.

Engineering geology of the study area

Based on engineering geology maps and it's slicing (with modifications) from Irvani *et al.* (2013) and Irvani (2013) in Figure 3 and 4, Sandstone Unit with an 8.8 Hectares area has a property slightly – moderately weathered, altered, compact, very strong jointed, compressive strength (UCS) ranging based on rebound value of Schmidt hammer from 143.25 - 241.99 MPa. Granite Unit properties in exposed approximately 393 Hectares area is crystalline, fresh – moderately weathered, very compact, jointed, strength (UCS) between 252.14 – 289.71 MPa. Mudstone Unit in 236.2 Hectares area and Pebbly Sandstone within 87 Hectares area has main engineering properties is moderately weathered, not yet compacted well (cohesive), with a compressive strength (UCS) 2.93 MPa. Pebbly – Muddy Coarse Sand in 469 hectares

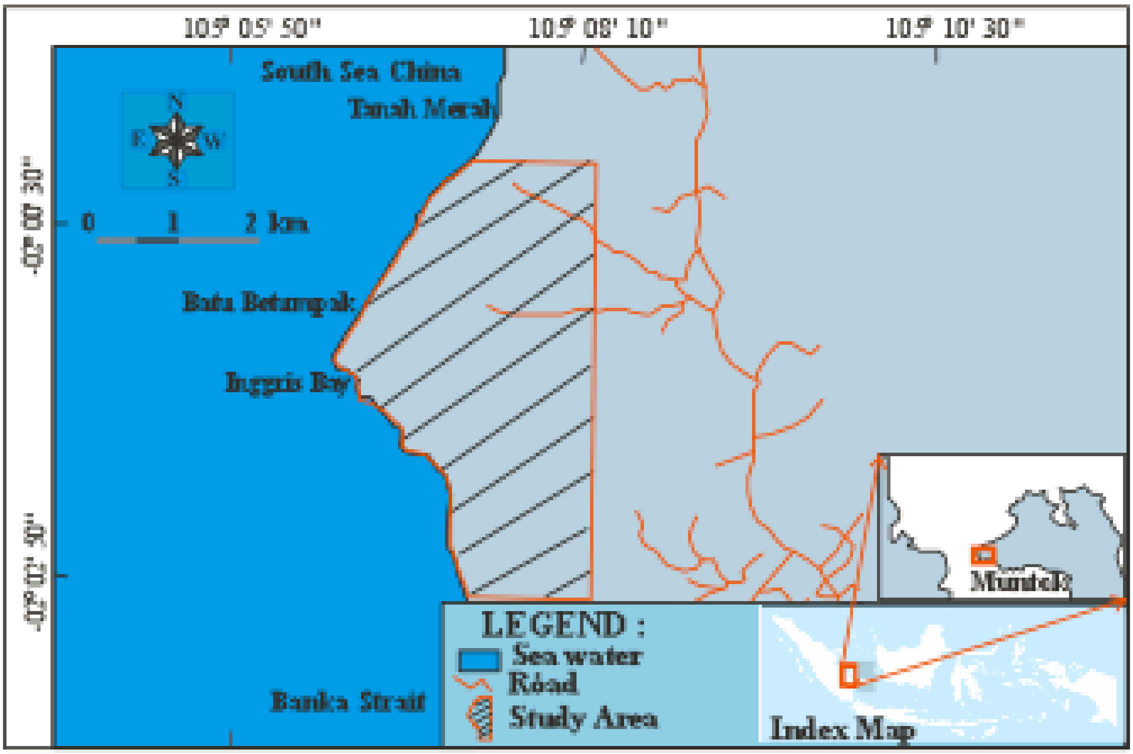

Figure 1: Study area map.

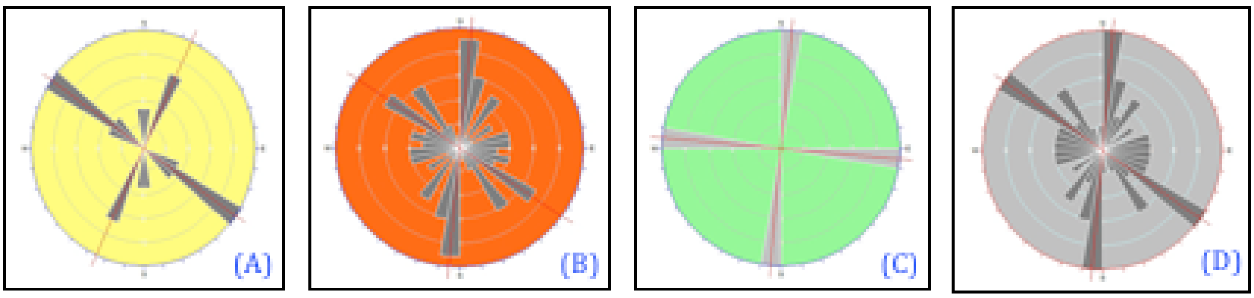

Figure 2: Principle Discontinuity orientation: (A) Sandstone, (B) Granite, (C) Mudstone, (D) All unit of rock.

area, and Fine – Coarse Sand in 41.8 Hectares Area covered Granite and Sandstone Units, has depth in a few meters to over 80 meters, cohesive until slightly loose properties, and estimated as the result of weathering and alteration of rocks.

Rock mass quality classification based on rock mass rating (RMR)

Observations point of 30 surface data and subsurface data about 20 drilling points to be the basic of rock mass quality evaluation. Engineering geology map becomes the reference in determining the distribution, depth and boundary of rock mass RMR quality.

Sandstone Unit has limited surface data in 3 observation station, it's basic RMR is 53.75–62, with corrected RMR is 31.25–42, which showed poor – medium quality, which is generally poor quality. Subsurface data of Sandstones recorded at BBH-13 points and BBH 14 drilling point that has weathered and altered, present in considerable depth and are not dominant to be a part of Sandstone Unit, where the rocks have the basic RMR and corrected RMR values is small, is each ranged from 36.26–37.25 and from 25.25–26.26, with poor quality. The rock mass quality state is affected by space density and slope orientation of discontinuities, the presence of filling, degree of weathering or alteration, as well groundwater condition.

Granite Unit has a very poor – very good quality, with moderate quality in general. Surface data about 24 stations observation has basic RMR between 62.33–100, corrected RMR is 41.33–100, has been moderate – very good quality, with moderate quality in general. Subsurface data (drilling point of BBH-01, BBH-01A, BBH-02, BBH-03, BBH-04, BBH-06, BBH-06A, BBH-07, BBH-07A, BBH-12, BBH-12A and BBH-14A) have the basic RMR between 29–87, corrected RMR is 4–77, and has very poor – good quality, with moderate general quality. The rock quality is influenced by density space and orientation of discontinuities, weathering, filling, as well groundwater condition, where the quality of surface data tends better than the subsurface data, because it has less space and fresh rock condition, as well above the groundwater table.

The number of surface data of Mudstone Unit is very limited, only one observation station, with the value of basic RMR is 50.67, corrected RMR is 33.34, so has poor quality. Subsurface data at four drilling points (BBH-08, BBH-09, BBH-10 and BBH-11) have a range value of basic RMR is 46.34–50.67, corrected RMR between 29.01–33.34, with poor quality. The rock quality is affected by low compressive strength (UCS) of rock, the discontinuities slope is quite high, moderate grades of weathering, and the shallowness of the water table which is characterized by the presence of artesian wells at BBH-10 and BBH-11 drilling point.

Pebbly Sandstone Unit also has limited number of surface data at two station observations, has basic RMR and corrected RMR is 54, with moderate quality. Subsurface data at the BBH-03 drilling point has value of basic RMR and corrected RMR is 54, with moderate quality grade. The rock quality is influenced by the low compressive strength (UCS), and moderate weathering grade.

Rock mass quality based on RMR classification

Based on the RMR value of rock mass, Granite and Pebbly Sandstone Unit with moderate general quality of rock mass was having estimated the range values of cohesion is 0.2–0.3 MPa, the internal friction angle between 25–35°, and the allowable bearing pressure is 280–135 T/m^2. Both of Sandstone and Mudstone Units have poor rock mass quality, has estimated value of cohesion between 0.1–0.2 MPa, internal friction angle value is 15–25°, and estimated allowable bearing pressure between 135–45 T/m^2.

Rock mass quality and capacity based on geological strength index (GSI) classification

Rock mass GSI quality evaluation and its capacity have been discussed in detail in Irvani *et al.* (2013) and Irvani (2013). Variety and the best quality are owned by Granite Unit (GSI = 27–95) with good general quality, whereas for the Sandstone Unit (GSI = 44–55), Mudstone Unit

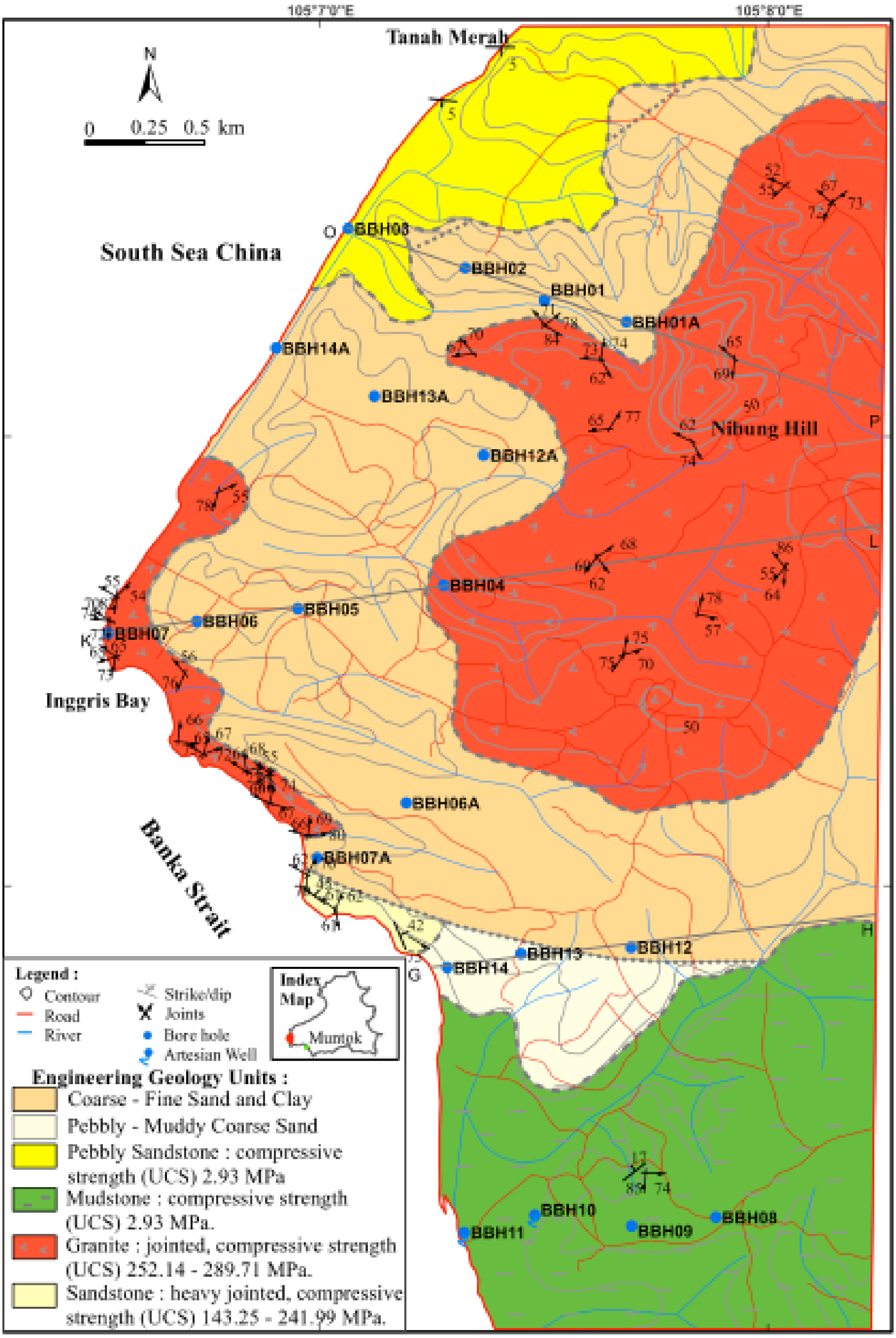

Figure 3: Engineering geology map.

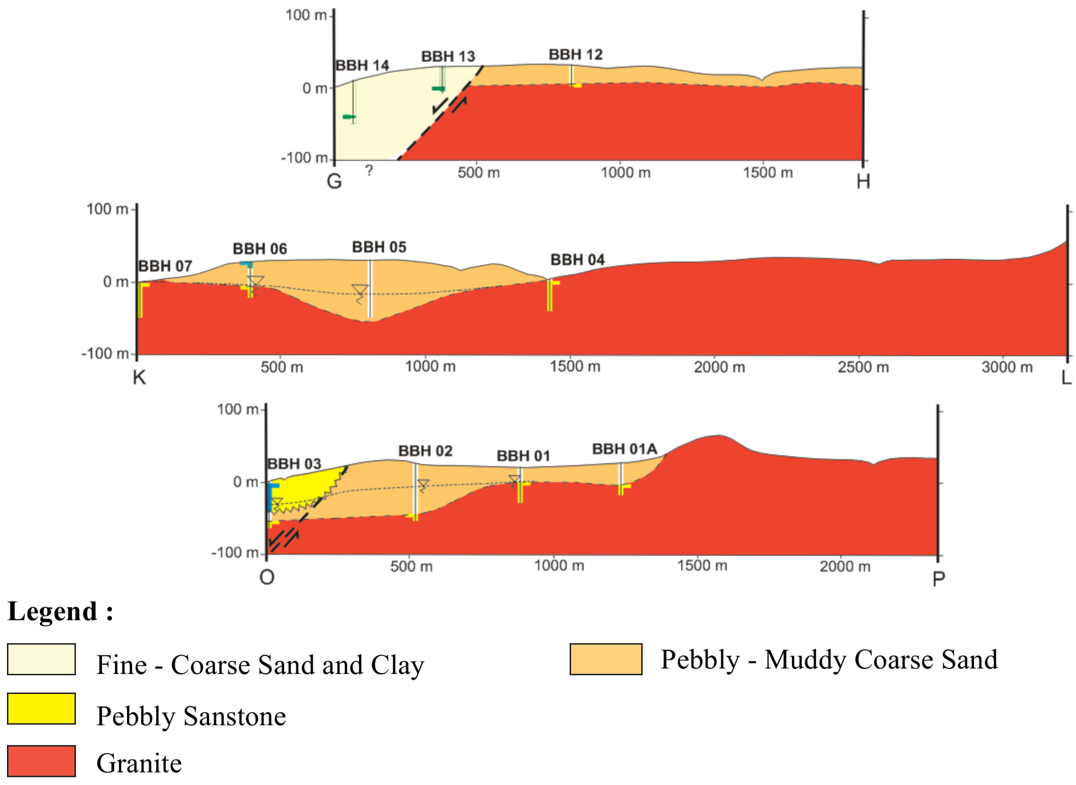

Figure 4: Engineering geology map cross-section G-H, K-L and O-P.

(GSI = 39–43) and Pebbly Sandstone Unit (GSI = 42) all being moderate quality.

The result of rock capacity calculation shows the variation of value and high capacity at Granite Unit. Granite Unit has compressive strength (UCS) between 1.0465–183.8 MPa, tensile strength in a range (-0.0122)–(-5.2625) MPa, the rock mass strength between 24.5244–220.351 MPa, as well variations of modulus deformation between 1.73–86.68 GPa with an average high value. Sandstone Unit has compressive strength (UCS) between 2.3079–7.7621 MPa, tensile strength range (-0.2131)–(-0.0546) MPa, the rock mass strength between 16.3223–33.1094 MPa, and the large of deformation modulus between 4.60–8.67 GPa. Mudstone Unit has compressive strength (UCS) is 0.0317 MPa, tensile strength is -0.003 MPa, the rock mass strength is 0.1373 MPa, and modulus of deformation is 3.45 GPa. Pebbly Sandstone Unit has compressive strength (UCS) is 0.0403 MPa, tensile strength is -0.0009 MPa, the rock mass strength is 0.3135 MPa, and modulus of deformation is 4.1 GPa.

Relationship between RMR and GSI classification

The limited amount of available data, especially for the surface data (outcrop) on Unit Sandstone, Mudstone and Pebbly Sandstone caused the results of analysis of the relationship between value of basic RMR and GSI on the third unit is not significant, significant results only showed by Granite Unit because it has rich amount of measurements data. Linear relationship basic RMR and GSI Granite Unit with regression factor is 0.759, indicating a strong relationship and it was formulated by the equation GSI = 0.739 (RMRbasic) + 12.097 as illustrated by Figure 5.

The best location for nuclear power plant site

Granite Unit is the most appropriate location for nuclear power plants site based on the quality and capacity of rocks evaluation using the RMR and GSI methods. However, not all parts of Granite Unit suitable for shallow foundation as raft foundation type, because it has thick

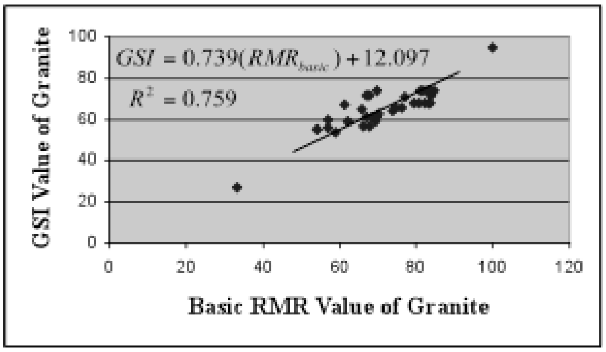

Figure 5: Linear relationship of basic RMR and GSI value of Granite Unit.

weathered rock or soil layers up to tens meters like at BBH-02, BBH-05, BBH-12A, and BBH-13A drilling points. Rock quality assessment based on RMR method uses adjustment value of discontinuity orientation for raft foundation type, so that a thick layer of soil and weathered rock become constraints in determining the location of nuclear power plants site. Granite Unit with an area about 393 Hectares is the suitable location for shallow foundation of nuclear power plants as in Figure 6, this is in line with the opinion that raised by Irvani *et al.* (2013) and Irvani (2013).

4 Conclusion

In general, the RMR rock mass quality in the study area is between poor and moderate, and the GSI rock mass quality is between poor and good. Granite Unit has the best quality from all lithology units. Granite Unit has distribution area about 393 Ha with a moderate RMR quality and a good GSI quality. Factors that affect the Granite Unit quality is the spacing density of discontinuity, filling, weathering, discontinuity orientation with respect to large slope, and groundwater flow conditions for subsurface data.

Based on the quality and bearing capacity evaluation of the rock mass using RMR and GSI classifications, the Granite Unit is considered to be the most appropriate location for the placement of nuclear power plants with the raft foundation type. Based on the RMR and GSI, the estimated cohesion value of the Granite Unit is 0.2–0.3 MPa, the internal friction angle is between 25° and 35°, allowable bearing pressure is between 280 and 135 T/m^2, compressive strength is between 1.0465 and 183.8 MPa, tensile strength is between -5.2625 and 0.0122 MPa, the rock mass strength is between 24.5244 and 220.351 MPa, and the large of deformation modulus is between 1.73 and 86.68 GPa.

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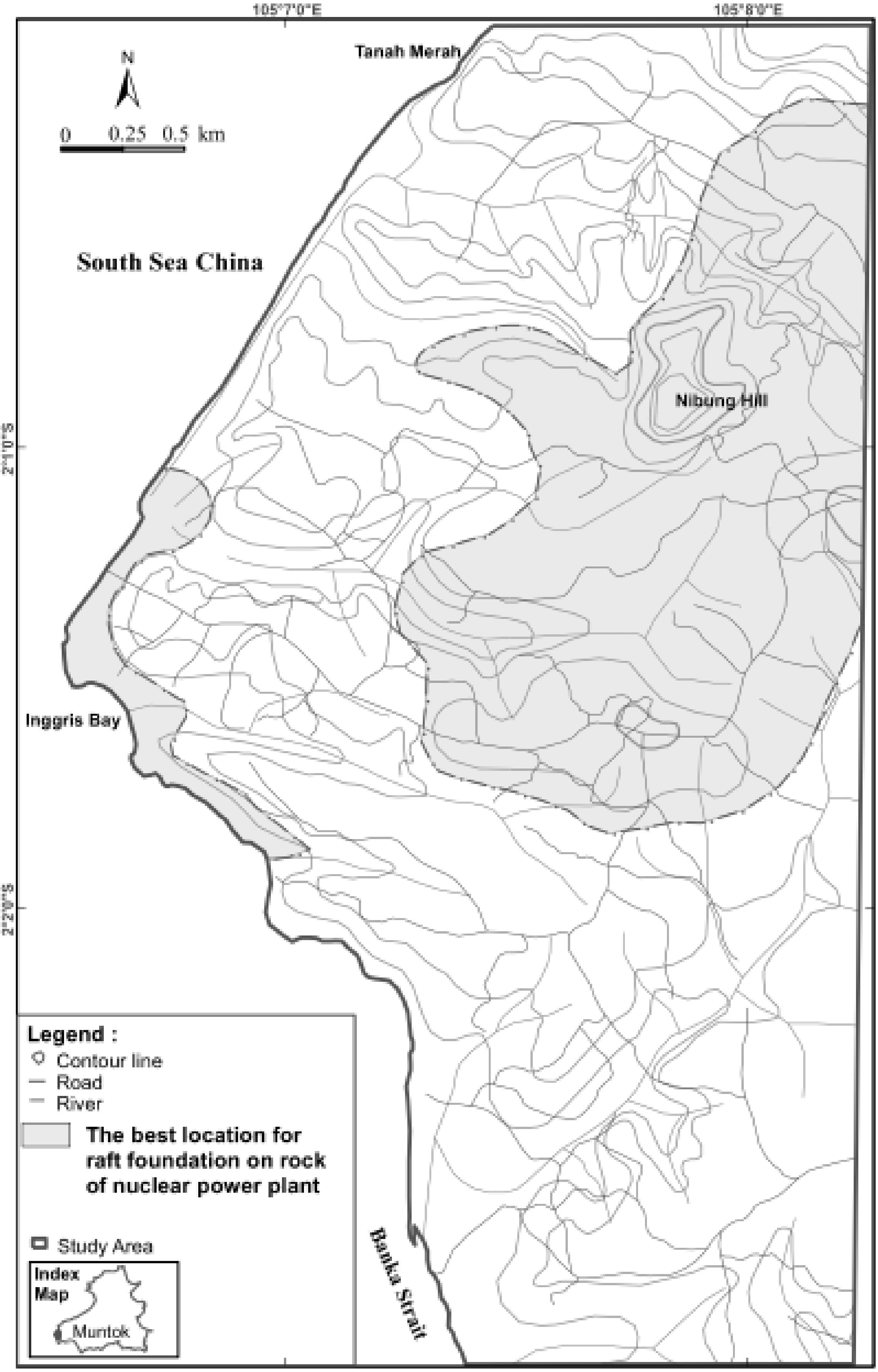

Figure 6: Suitability map for nuclear power plant site.

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