

GEOLOGICAL STRUCTURE ANALYSIS FOR POTENTIAL LANDSLIDE DISASTER AND MITIGATION AT TANJUNG KERAMAT AREA, GORONTALO

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Abstract - Geological structures in the form of joints and faults have big role in landslide disaster. This study aims to analyze the geological structures using stereographic analysis and rosette diagrams and determine the potential landslides that can occur in the research location in order to identify landslide mitigation efforts in the research area. The method used in this research is field observations then followed by stereographic analysis and rosette diagrams, which are one of the diagrams of the presentation of orientation of the geological structures elements. The results showed that the mechanism of landslide mostly caused by the geological structures distribution in the Tanjung Keramat area, especially by joint distribution. Tension joints dominant direction relatively west as well as the slope direction. Stereographic analysis of the shear joints show the type of extensional stress directing relatively North-South. Potential types of landslide that can occur are wedge failures. Appropriate mitigation efforts are by reducing the slope angle and making structural retaining walls to withstand natural slopes and heaps high enough.

Keywords: Geology, tuff, joint, wedge failure, retaining walls.

INTRODUCTION

The North Arm of Sulawesi divided into the western and eastern parts. The western part is called the Neck of Sulawesi. The eastern part is called the North Sulawesi Arc. The neck of Sulawesi is composed of basic volcanic rock and Cretaceous metamorphic rock. The North Sulawesi Arc is composed of acidic to basic volcanic rocks and basaltic rocks with pelagic sediment intercalations. The Gorontalo area is part of the North Sulawesi Arc which stretches from the middle to the west part of North Sulawesi Arc. Subduction of the Celebes Sea in north of Gorontalo area results in volcanic activity that produces volcanic rocks (Kavalieris, van Leeuwen, & Wilson, 1992; Bachri, 2006).

The existence of the Celebes Sea subduction has a great influences on seismicity in Gorontalo and reactivation process of faults (Koesnama, 2014). The existence of the Celebes Sea subduction zone, as shown in the seismic record, showed by the existence of a trench along the bottom of the continental slope of the North Arm of Sulawesi (Hamilton, 1973; Manyoe, Arif, & Lahay, 2019).

Geological structures that can be observed in the field and by remote sensing images are faults and folds. Normal faults are less irregular oriented in direction, but in the western part tend to be oriented east-west. Horizontal faults are paired with the direction of the right-lateral strike slip fault and left-lateral strike slip fault. Apandi & Bachri (1997) explained that the Gorontalo fault extends from northwest to southeast, starting from the Sulawesi Sea through Gorontalo till Tomini Bay.

Normal fault found in the Boliohuto Mountain shows a radiating pattern, while the horizontal fault is generally a right-lateral slip fault. The fault strike through old-aged rock unit (Tinombo Formation) to young-aged rock unit (Clastic Limestone Unit). The largest strike-slip fault is the Gorontalo Fault which based on the joint pattern analysis shows right-lateral movement direction (Apandi and Bachri, 1997). The morphology of northern part of Sulawesi Island showed four fault segments that divided the North Arm of Sulawesi (Hall & Wilson, 2000).

Geological structures in the form of joint and fault have a big role in the landslide disaster. Fractured rocks is a weak zones which is one of the entrances of water into the rock bodies. Weak zones reduced the shear strength of the rock to resist the rock movement and saturation process of water in the soil/rock which can increase in pore pressure in the soil/rock bodies. This condition eventually pushed the masses to move in a form of landslide.

Existing geological structures is a form of response of the earth forces so that landslide events are natural events that are often found in areas that have hilly or mountainous morphology with material in the form of soil or rock. In this study, the measurement is more emphasized on the joint measurements to determine the type and direction of the main stress regime and the type of landslide potential at the study site based on the joints distribution. The problems that will be discussed in this study are what are the effects of the main stress regime that form joints on rocks and landslide types based on the joints data to determine an efforts to mitigate or prevent landslides. The purpose of this study is to analyze the geological structures using stereographic analysis and rosette diagrams and determine the type of landslide potential that can occur so that landslide mitigation efforts can be made in the research area.

METHOD AND DATA

Administratively, research area is located in Tanjung Kramat Village, Gorontalo City. Geographically it is bordered by Pohe Village in the north, Tomini bay in the south, Gorontalo Bay in the east, and Bongo village in the west. Astronomically it is in the coordinates N 0.4964° – 0.4970° and 123.0424° – 123.0457°. Measurement of geological structural elements is carried out on outcrops composed by tuffs.

The field equipment used in this study is a Garmin GPS (Global Positioning System) receiver, geological hammer, Brunton type geological compass, mineral comparator and grain size. Other equipment used is a 30x and 60x magnification loupe, 50 m roll meter, digital camera, sample bag, 0.1N HCL, geological stationeries and Douglas protractor.

Field data and information obtained by collecting geological structure elements by conducting orientation measurements and description of geological conditions in the field. Observation of rock outcrops and geometry measurements of 60 shear joints data and 80 tension joints data. Joints measurements are done by measuring the direction of the strike and the dip of the joint then recorded to a field notebook. The joints data will be correlated with slope condition

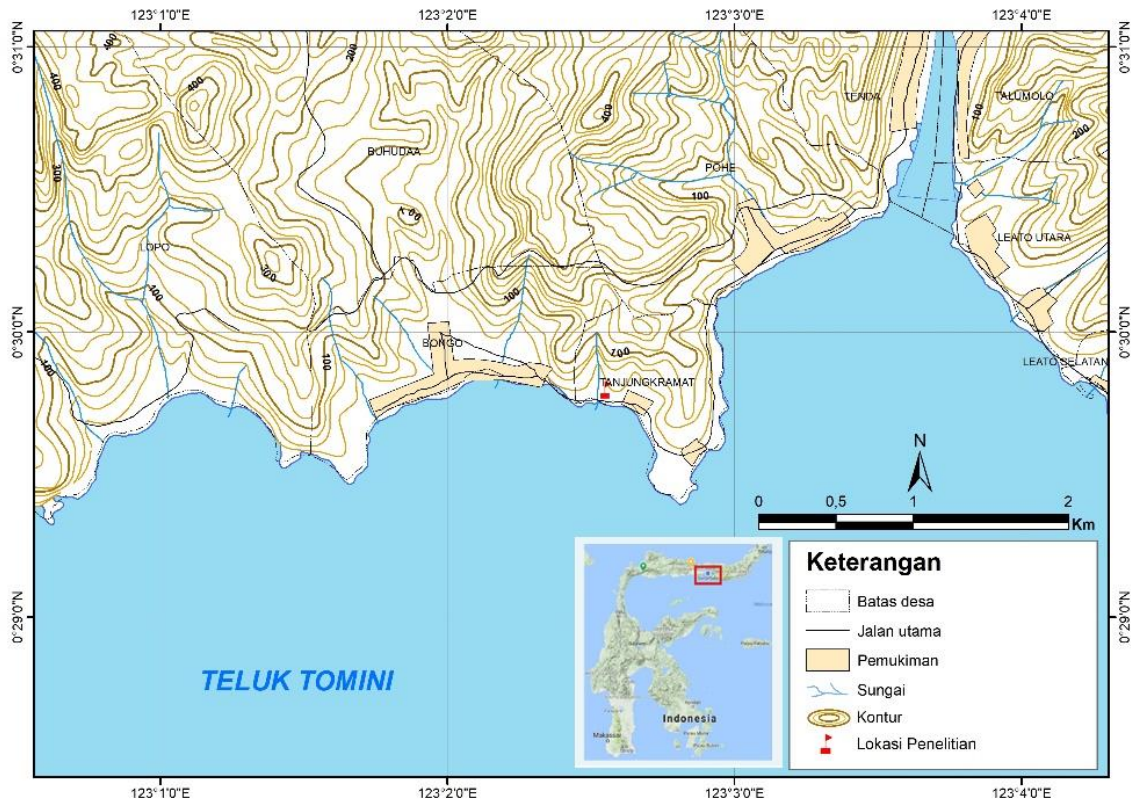


Figure 1. Research location map.

The method used in this research is the field survey method to collecting data then processing using stereographic projections to find out the type of main stress regime at the research area and the rosette diagram to determine the distribution of the dominant joints direction in research area. Stereographic projection is performed on a stereonet using equal angle projection. A standard rosette diagram is formed by centralized circles which are layered on a set of radial lines. The radius of each circle will be different and continue to grow outside the center of the circle which is a dominant data set or can be interpreted as the general direction of the entire measurement. The analysis was continued by determining the type of landslide potential based on the direction of the slope to the joints distribution at the research site. Landslide type uses the landslide failure classification by Hoek and Bray (1981).

The final stage of the research process is the interpretation of field data. The results of studio data processing and the results of geological structures analysis are interpreted to determine the disaster prevention steps or mitigation efforts based on research data.

RESULTS AND DISCUSSION

Based on regional geology (S Bachri, Sukido, & Ratman, 1993), the study area is located in the reef limestone unit (Ql). Reef limestone is composed of coral limestone which estimated to be Pleistocene to Holocene. Based on stratigraphic sequence, reef limestone is located above the Pinogu Volcanics (TQpv) which is composed of agglomerates, tuffs, and basaltic-andesitic lava. Pinogu Volcanics estimated to be Pliocene to Pleistocene age (Figure 2).

Outcrops located at the roadcut with high vegetation levels. The direction of the slope is relatively westward with a steep slope (80°). Outcrops are composed by tuffs. The rocks are characterized by grayish white, the matrix is composed of tuffs, gravel to pebble-sized fragments, matrix-supported, tuff grain size, good in porosity, good in permeability, non-carbonic, rather compact. Outcrop has been jointed intensively.

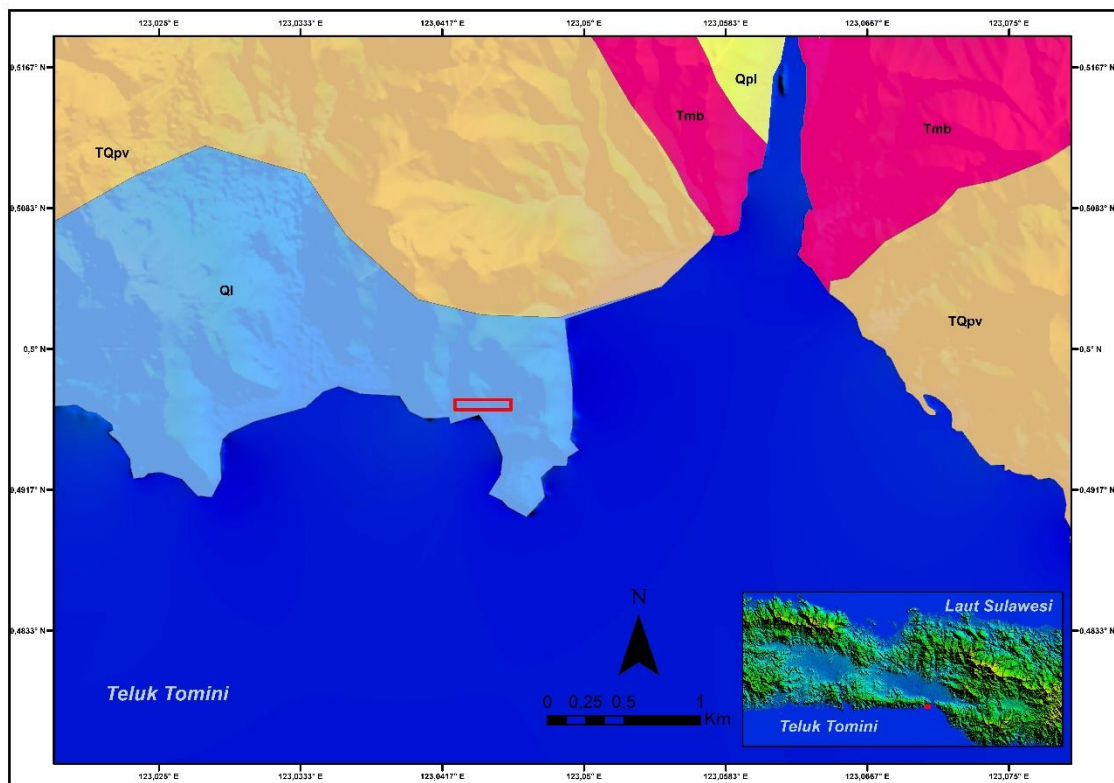


Figure 2. Regional geology of research location.

The joint observed in the field consists of the tension joint and the shear joint (Figure 3). Tension joint is the result of tensional stress and shear joint is the result of compressional stress. According to Angelier (1979), relative motion along geological structures is controlled by the prevailing stress tensor.

The tension joint at the research area characterized by rough surface and irregular in directions. These characteristics can result the break off chunks out of rock outcrop. The joint shape is almost vertical and tends to follow the outcrop.

Shear joint is characterized by the closed joint surface, showing symptoms of fine shearing, generally paired with a range of between 5 till 35 centimeters and a length of 4 till 10 meters. Shear joint has a nearly vertical dip angle and not influenced by tur outcrop shape.



Figure 3. Joints distribution at the outcrop.

Table 1. Measurement results of tension joint in the research area.

No	Strike N...°E	Dip °	No	Strike N...°E	Dip °	No	Strike N...°E	Dip °	No	Strike N...°E	Dip °
1	59	58	21	254	86	41	36	56	61	52	80
2	123	82	22	116	85	42	182	86	62	90	83
3	161	88	23	243	81	43	246	89	63	105	81
4	32	56	24	38	76	44	231	82	64	295	85
5	231	86	25	260	84	45	60	81	65	253	84
6	250	87	26	253	83	46	54	58	66	68	85
7	251	80	27	258	85	47	253	86	67	236	80
8	71	73	28	66	68	48	120	80	68	210	82
9	262	83	29	260	85	49	110	81	69	233	86
10	268	81	30	250	80	50	97	81	70	263	87
11	241	85	31	245	86	51	40	77	71	71	74
12	45	41	32	31	80	52	110	88	72	260	84
13	236	84	33	240	80	53	55	85	73	106	81
14	244	90	34	251	80	54	134	86	74	122	84
15	262	81	35	258	84	55	70	86	75	246	86
16	104	60	36	31	78	56	54	77	76	86	55
17	274	86	37	280	86	57	240	80	77	250	84
18	262	80	38	270	84	58	256	86	78	250	84
19	276	87	39	268	85	59	126	81	79	218	82
20	112	47	40	27	81	60	93	82	80	60	74

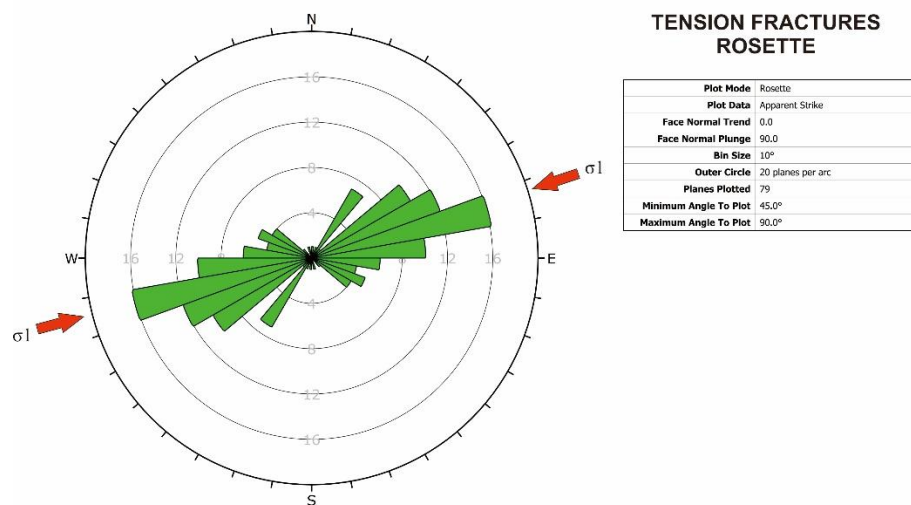


Figure 4. Rosette diagram of tension joint in the research area.

Table 2. Measurement results of shear joint in the research area.

No	Strike N...°E	Dip °	No	Strike N...°E	Dip °	No	Strike N...°E	Dip °
1	75	72	21	268	75	41	110	60
2	264	72	22	95	79	42	148	72
3	92	40	23	140	79	43	221	85
4	274	71	24	92	61	44	84	50
5	55	60	25	283	72	45	245	81
6	240	83	26	81	67	46	87	46

7	63	67	27	124	81	47	62	45
8	292	71	28	66	64	48	230	29
9	43	66	29	264	50	49	265	72
10	251	84	30	65	60	50	85	44
11	85	53	31	74	60	51	80	35
12	242	65	32	273	70	52	244	80
13	55	69	33	75	42	53	70	46
14	286	60	34	242	76	54	223	88
15	55	68	35	91	45	55	91	56
16	271	65	36	225	70	56	256	65
17	70	54	37	241	80	57	71	35
18	283	71	38	34	29	58	235	74
19	139	85	39	89	72	59	104	45
20	80	58	40	231	75	60	229	79

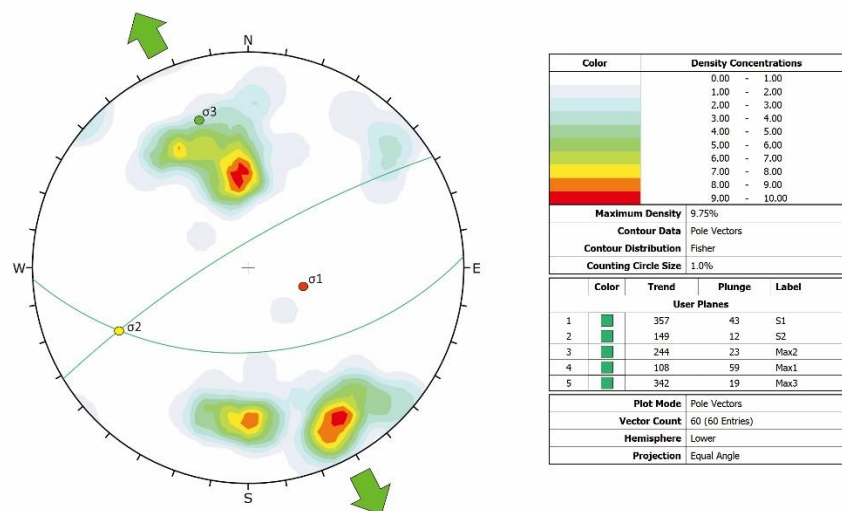


Figure 5. Stereographic analysis of shear joint in research area.

Joint measurements in the study area were carried out in the tuff unit outcrop. The results include the measurement of the tension joint and the shear joint. The tension joint analyzed using a rosette diagram to obtain a joint main direction. Shear joint analyzed using stereographic projection to determine the main stress regime that control the study area and their relation to landslide.

Main direction of tension joint is relatively East-West direction which is indicated by the distribution of measured measurements with dominant directions N 75 °E and N 255 °E. This general direction of muscularity represents the direction of maximum stress (σ_1) in the study area. The direction of this maximum stress is relatively same as the direction of the slope.

Stereographic analysis of shear joint was performed on 60 shear joint data from field measurements. The results obtained the value of maximum stress (σ_1) 59 °E: N 108 °E, medium stress (σ_2) 23 °E: N 244 °E, and minimum stress (σ_3) 19 °E: N 342 °E. The results of this analysis showed the type of extensional stress regime directing relatively to North-South.

The landslide type based on the results of the joint analysis of the slope is shown in Figure 6. In the figure it appears that there are two main joint planes with the intersection direction relatively same as direction of the slope. This condition indicates that the type of landslide that can occur at the research site is a wedge failure based on Hoek and Bray (1981) with potential landslide disaster directing to West.

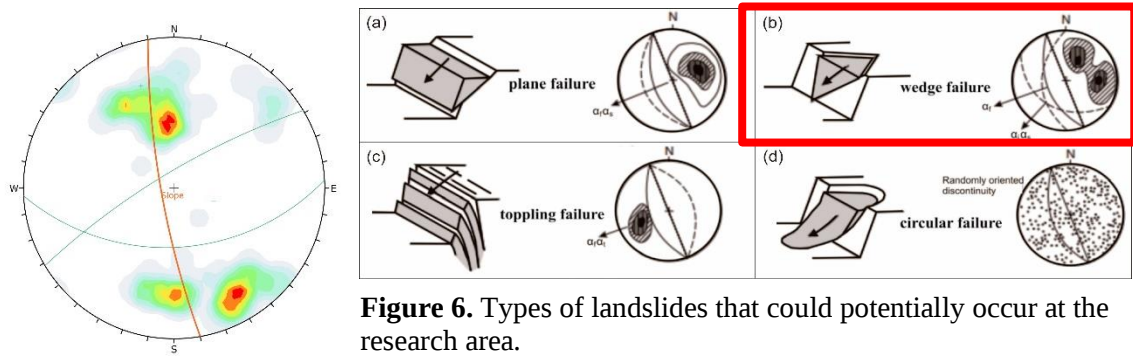


Figure 6. Types of landslides that could potentially occur at the research area.

The landslide mechanism that occurred in the Tanjung Keramat area, Gorontalo City, Gorontalo Province was generally influenced by the presence of joints on the outcrops. Joint orientation that same as the direction of the slope or cliff reduce the stability of the slope and rock chunks tend to be easy to move. This condition is exacerbated by high vegetation levels on the rock outcrops with high fracture intensities. High fractures intensity can be a pathway for the entry of meteoric water into the rock body, thereby increasing the level of rock saturation and encouraging landslides.

The recommended mitigation efforts is to reduce the slope angle. Reduce slope angle is a relatively inexpensive way to repair of the slope. Slope repairs are usually carried out on roadcut with landslide potential to be happen on steep slopes. If the slope angle repairs are done the same as the previous slope angle, then the landslide will still occur again. The action that must be taken is reduce the slope angle than the previous slope angle or increase the stability of the slopes by using geotechnical preventive solution.

Other mitigation efforts that can be done are by building structural retaining walls. Structural retaining walls are generally made to withstand natural slopes and heaps that are quite high both in the highlands and lowlands areas which have quite large differences in flood water levels. So the retaining wall is needed to hold the landslide at a steep slope that makes to increase the resisting forces of the slope.

CONCLUSION

The landslide mechanism caused by the geological structures in the research area, especially controlled by the joints distribution. Joint orientation mostly directing relatively West as well as the slope direction. The results of stereographic analysis showed an extensional stress regime type with a relatively North-South in direction. Potential types of landslide that can occur are wedge failures. Appropriate mitigation efforts are to reduce the slope angle and make structural retaining walls which are generally made to withstand natural slopes and heaps that are quite high.

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