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Full Length Research Paper

Sensitivity analysis of slopes affected by possible earthquake loading and heavy rainfall: Case study

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The effect of seismic loading on slope failure is studied both experimentally and analytically to establish the spatial and temporal process of failure initiation and propagation during possible earthquake loading or heavy rainfall. For such purpose different limit equilibrium modeling were carried out and factor of safeties against sliding caused by both excess earthquake loading and heavy rainfall were found. As for this study, two parameters normally taken into account which were soil properties changing as well as exerted seismic loading. Moreover to show the reality and importance of the main objective of this research, two of the constructed slopes in Malaysia were selected and modeled. The factor of safety against landslides in normal condition (without any extra seismic loading consideration) at Johor was 1.293, 1.425 and 1.301 using ordinary, bishop and Janbu methods, respectively. Also, factor of safety against slope failure at Besut was 1.508, 1.637 and 1.519 according to ordinary, bishop and Janbu methods, respectively. As a result, mentioned slopes will collapse applying even low seismic loading of 0.2 g. Internal friction angle reduction more than 25% also caused significant decrease in the slope's factor of safety.

Key words: Geotechnical engineering, slope stability, stability analysis, landslides, earthquake, rainfall.

INTRODUCTION

The evaluation of slope stability analyses in geotechnical engineering has followed closely the developments in soil and rock mechanics as a whole. The increasing demand for engineered cut and fill slopes on construction projects has only increased the need to understand analytical methods, investigative tools and stabilization methods to solve slope stability problems (Moayedi et al., 2009; Moayedi et al., 2010a-c; Moayedi et al., 2011a-f). Slope stabilization methods involve specialty construction techniques that must be understood and modeled in realistic ways. An understanding of geology, hydrology and soil properties is central to applying slope stability principles properly. Analyses must be based upon a model that accurately represents site subsurface conditions, ground behavior and applied loads. Judgments regarding acceptable risk or safety factors must be made to assess the results of analyses (Anderson and Richard, 1987; Moayedi et al., 2010d (15D)).

Landslides, as one of the major natural hazards, account each year for enormous property damage in terms of both direct and indirect costs. Landslides, defined as the movement of a mass of rock, debris or earth down a slope (Cruden, 1991), can be triggered by a variety of external stimulus, such as intense rainfall, earthquake shaking, water level change storm waves or rapid stream erosion that cause a rapid increase in shear stress or decrease in shear strength of slope-forming materials. In addition, as development expands into unstable hillslope areas under the pressures of increasing population and urbanization, human activities such as deforestation or excavation of slopes for road cuts and building sites, etc., have become important triggers for landslide occurrence. Landslides have caused large numbers of casualties and huge economic losses in mountainous areas of the world. The most disastrous landslides have claimed as many as 100,000 lives (Ataei and Bodaghabadi, 2008). In the United States, landslides

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Table 1. Soil properties at Johor.

	Cohesion (kPa)	Unit weight (kN/m³)	Internal friction angle (degree)
Top layer	10	18	30
Bottom layer	20	10	35

Table 2. Soil properties at Besut.

	Cohesion (kPa)	Unit weight (kN/m³)	Internal friction angle (degree)
Embankment fill	5	19	33
Alluvial soil (AS)	1	18	29
Ross silt (RS-II)	0	18.5	32
Ross silt (RS-IV)	0	19	33
Highly weathered rock (HWR)	1	20	35

cause an estimated US$1 to 2 billion in economic losses and about 25 to 50 deaths annually, thus exceeding th e average losses due to earthquakes (Schuster and Fleming, 1986). Ataei and Bodaghabadi (2008) conservatively estimated that in China the number of deaths caused by landslides totaled more than 5000 during the 1951 to 1989 period, resulting in an average of more than 125 deaths annually, and annual economic losses of about US$500 million.

Social and economic losses due to landslides can be reduced by means of effective planning and management. These approaches include:

(a) restriction of development in landslide-prone areas, (b) use of excavation, grading, landscaping and construction codes, (c) use of physical measures (drainage, slope-geometry modification and structures) to prevent or control landslides and (d) development of warning systems. Schuster and Leighton (1988) estimated that these methods could reduce landslide losses in California by more than 90%. Slosson and Krohn (1982) stated that enactment of these approaches had already reduced landslide losses in the city of Los Angeles by 92 to 97%. However, in spite of improvements in hazard recognition, prediction, mitigation measures and warning systems, worldwide landslide activity is increasing.

A change in the stability of a slope can be caused by a number of factors, acting together or alone. Natural causes of landslides included the groundwater (pore water) pressure acting to destabilize the slope, loss or absence of vertical vegetative structure, soil nutrients and soil structure (e.g. after a wildfire), erosion of the toe of a slope by rivers or ocean waves, weakening of a slope through saturation by snowmelt, glaciers melting or heavy rains, adding loads to barely-stable slope, earthquake-caused liquefaction destabilizing slopes and volcanic eruptions (Asadi et al., 2011; Cheng and Lau, 2008; Moayedi et al., 2010e (15N)).

MATERIAL AND METHODS

Study area

As for risk assessment analysis, two different study areas in Johor and Besut were selected to estimate the effect of unmoral seismic loading as well as the effect of heavy rainfall through them. Johor is located at 1°57'52' N and 103°27'40" E. The slope that has been investigated in this area included two layers. On the other hand, second location was in Besut area. Besut is located at 5°44'57"N and 102°33'51". Table 1 and 2 showed soil layer properties for Johor and Besut areas. Both slopes in Johor and Besut are shown in Figures 1 and 2, respectively.

Limit equilibrium modeling

As for analysis of mentioned slopes, slope/w was selected since it is formulated in terms of moment and force equilibrium factor of safety equations. For example, the Morgenstern-price method satisfies both force and moment equilibrium (Moayedi et al., 2011g). This general formulation makes it easy to compute the factor of safety for a variety of methods and to readily understand the relationships and differences among all the methods. GEOSLOPE allows geotechnical engineers to carry out limit equilibrium slope stability analysis of existing natural slopes, unreinforced man-made slopes or slopes with soil reinforcement. GEOSLOPE can use finite element computed stresses to calculate a stability factor by computing both total shear resistance and mobilized shear stress along the entire slip surface. GEOSLOPE then computes a local stability factor for each slice. Probabilistic analysis can be performed by using normal distribution functions to vary soil properties and loading conditions. In the present study, slope/w computed the slope stability analysis by using three different methods in order to obtain the value of factor of safety (FOS) under a variety of seismic loads as well as soil characteristics. The three methods were ordinary, bishop, and Janbu methods. To interpret the result, factor of safety against seismic load, cohesion and internal friction angle were plotted under the mentioned methods.

RESULTS AND DISCUSSION

Figures 3, 4 and 5 showed the effectivenes of extra

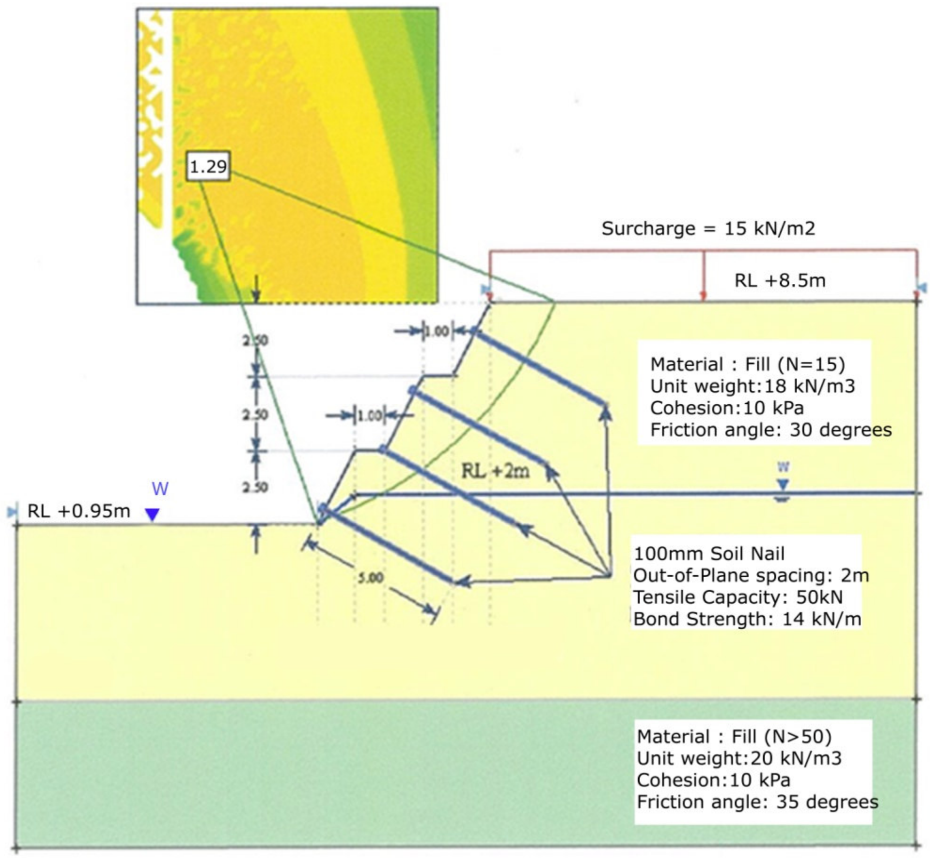

Figure 1. Soil layer at Johor.

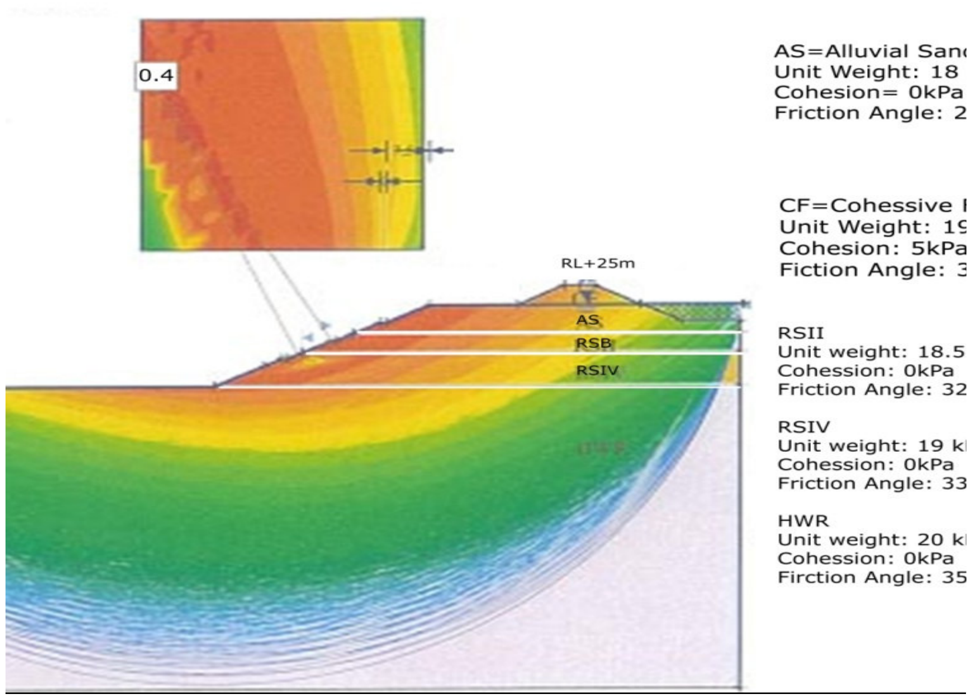

Figure 2. Soil layer at Besut.

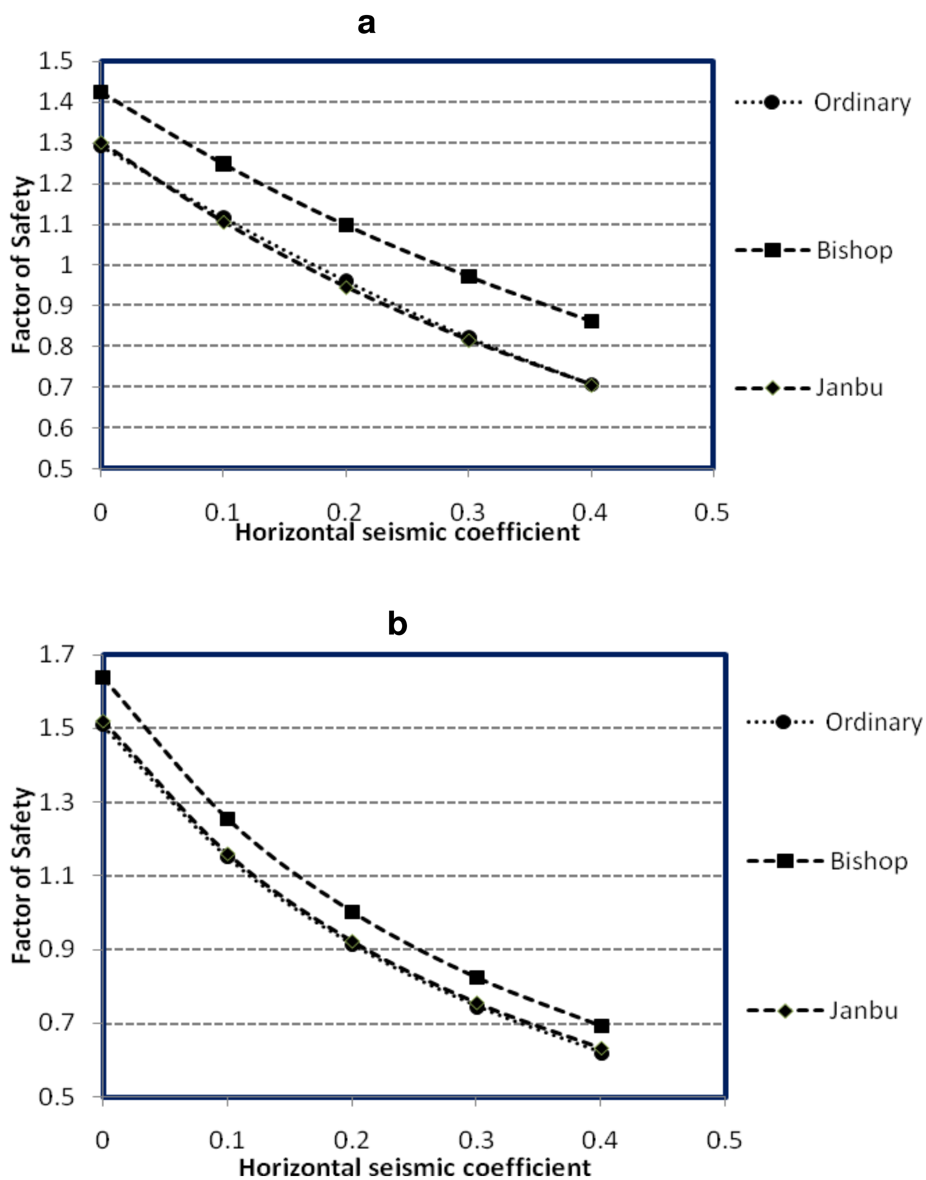

Figure 3. Comparing effect of seismic loading on slope's factor of safety in different methods, (a) Johor slope and (b) Besut slope.

loading on factor of safety of slope's in both Johor slope and Besut. All three parameters, horizontal seismic coefficient, cohesion of soil and internal friction angle of the soil were considered as a variable to find their effects on factor of safety of slopes. Such parameters might be altered by exerting any further possible seismic loading or reduction in soil shear strength parameters. This could be caused by heavy rainfall which mostly happen in Malaysia. As shown in Figure 3, factor of safety decreased gradually with the increasing of the seismic load, whereas factor of safety without earthquake loading was 1.3 and by adding seismic loading decreased remarkably to 0.8 as for horizontal seismic coefficient of 0.3. It is noteworthy that, bishop results showed the higher value as compared to the other methods. Also, as shown in Figures 4 and 5 the reduction in Besut slope has been more considerable than the Johor slope.

As mentioned, landslides occur when the stability of a slope changes from a stable to an unstable condition. A change in the stability of a slope can be caused by a number of factors, acting together or alone. One of the natural causes of landslides is earthquakes adding loads to barely-stable slope. Design for seismic loading was mostly avoided or not being cared enough for in slopes around the Malaysia. However, after huge earthquake happened in Japan in March, 2011 it is now very important to stabilize the slopes that may failed during the possible seismic loading.

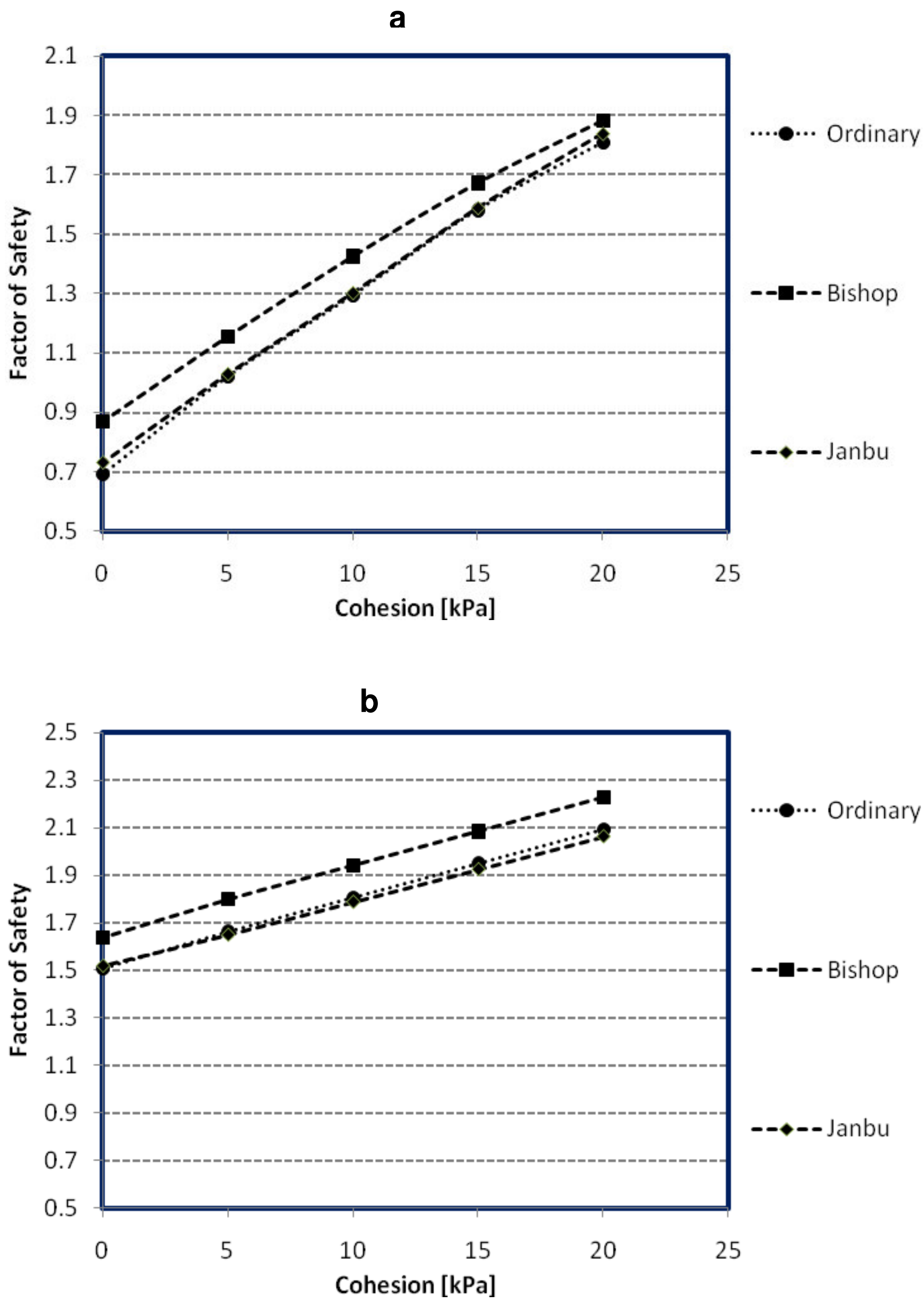

Figure 4. Comparing effect of cohesion changing on slope's factor of safety in different methods,(a) Johor slope and (b) Besut slope.

Conclusions

In present study different slope analysis were carried out to find the effectiveness of soil strength characteristics as well as seismic loading on some available slopes in Malaysia. The results clearly show that the slopes failed in their critical condition. Such critical condition described as exerting abnormal loading and heavy rain fall. Both of the mentioned loads have a significant effect on factor of safety reduction. As for results, in normal condition (without mentioned loads), factor of safety for slope in Johor area was 1.293 according to ordinary method, 1.425 by applying bishop method and 1.301 regarding Janbu method. On the other hand, factor of safety for normal condition for Besut was 1.508 according to ordinary method, 1.637 by applying bishop method and regarding Janbu method was 1.519. Surprisingly, mentioned factor of safety reduced more than 50% by

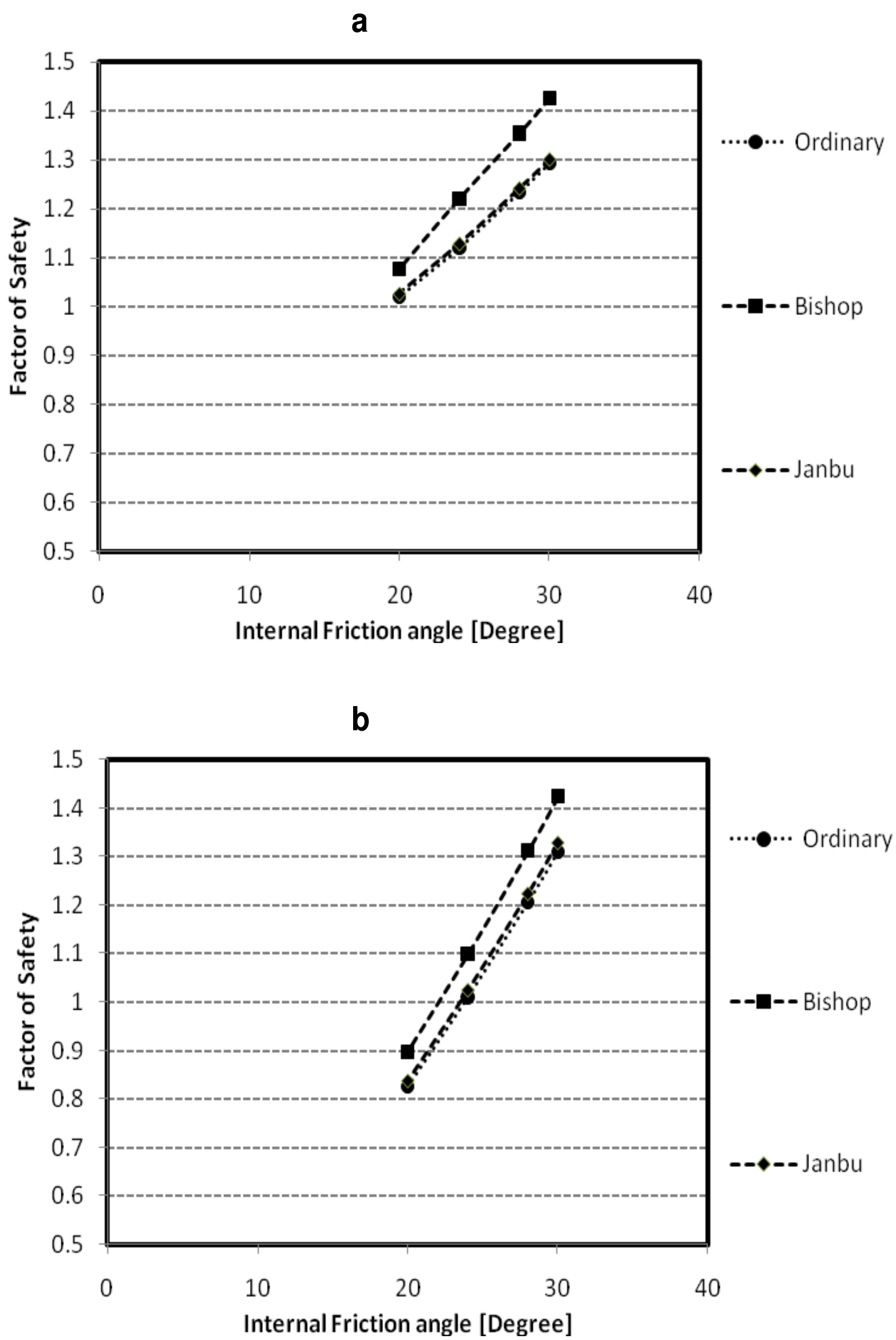

Figure 5. Comparing effect of Internal friction angle changes on slope's factor of safety in different methods, (a) Johor slope and (b) Besut slope.

applying 0.3 g of horizontal earthquake coefficient. The decreasing of factor of safety can be hazardous to the environment and human when landslide or slope failure can occur. To increase the factor of safety of the slope, we can provide some slope repair such as geogrid, utilizing baled tire fill and also slope injection by chemical to increase the factor of safety at slope.

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