PRECISION OF DEM AND ITS INFLUENCE ON A RESULT OF A SEISMIC STABILITY ANALYSIS OF SLOPE

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ABSTRACT :

In this study, the precision verification was performed about DEM (Digital Elevation Model) with the 10m grid spacing, and examined about the influence on a result of a seismic stability analysis of slope which is based on the features analysis of the micro-topography. As the results, it founds that the safety factors by the seismic stability analysis of slopes with DEM are very different from the safety factors which were calculated with the use of field surveying terrain information, because it became an average on the elevation values and became a smooth slope in case of using the DEM with 10m grid spacing.

KEYWORDS: Digital Elevation Model, Topographical Map, Slope, Seismic Stability Analysis

1. INTRODUCTION

The intensity of land use was measured in the hilly land and around at the country which has many precipitous mountains and slope area, and slope failure and landslide are happened in each place due to the earthquake and the heavy rain. As the slope disaster brings down the great economic loss and human damages, it is a big social problem (Sassa K. et al. 1996). It is, therefore, important to predict the danger points and take sufficient measures in advance. However, these damages are not a thing only by the external factor such as an earthquake and a heavy rain but also a geographical features form, a state of water content, vegetations and the history of the land formation are greatly influencing.

GIS (Geographic Information Systems) which social concern rises recently is shown as one tool for such a danger point prediction (Onozato K. et al. 1998, K.J. BEVEN et al. 1979, Takashi Okimura et al. 1988). GIS can deal with various problems in the space with the system for preparation not only to keep a map on the computer system for control and usage but also to use the information distributed geographically as space information which shows a position and attribute information which shows nature. Information can be looked up easily by the thing that a consolidation indicated varied information on the virtual space where the actual space was mapped, and the visual examination, analysis, presentation tied to the map more becomes possible. In consequence, it has the wide application of GIS endlessly, and it is used in many fields such as the geography, the city planning and environmental protection. At the same time, the DEM is as one of the important data on GIS. As DEM has height information in every unit mesh, it provides the opportunity of the modeling and analysis which relates to the geographical features on GIS. So, the use of DEM has been advanced rapidly in many fields of the natural and the cultural sciences. The information about the risk of the disaster can be analyzed and the information are connected with the discovery of the danger point by laying it on the map on GIS by using DEM and it becomes possible that measure is taken.

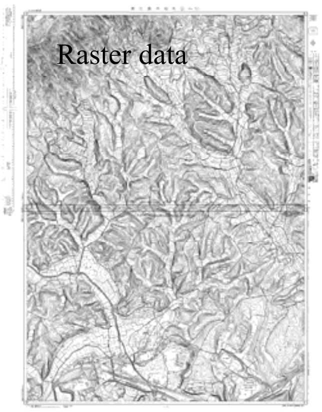
In previous study, the risks of disaster are evaluated by GIS and DEM, for example (Guoyun Zhou et al. 2004). It propose applying a three-dimensional slope stable mechanical model to the natural geographical features of the third complex form as same direction can consider slope unit for a wide area. Furthermore, quantification of the geographical features character (height above sea level, the degree of inclination and the inclination direction) was proposed.

By the way, DEM is formed based on the three-dimensional terrain data with the elevation values. A grid spacing of DEM is decided under considering the scale of the topographical map and the city planning map, contour intervals and the amount of formed data. Of course, though even DEM of what kind of grid spacing can be formed, if these resolutions and the limitation of the amount of formed data are ignored. But the precisions to the resolutions become very vague and it is very important problem to be considered.

2. THE DIGITIZATION OF THE TOPOGRAPHICAL MAP AND PREPARATION OF DEM

In previous study, though the author examined the predisposing factor of disaster by using 50m mesh DEM at before and after reclaimed, a mesh interval was too rough to investigate in the level of the size of each house, and it was pointed out that the high-resolution DEM are required with a detailed mesh from large-scale topographical map such as a city planning map to discuss in detail. Therefore, how to make detailed three-dimensional geographical features mesh data from the 1/2,500 large-scales topographical map is shown, and the contents of preparing high precision DEM are mentioned in this study. The preparation process of the three-dimensional geographical features mesh data is as the following.

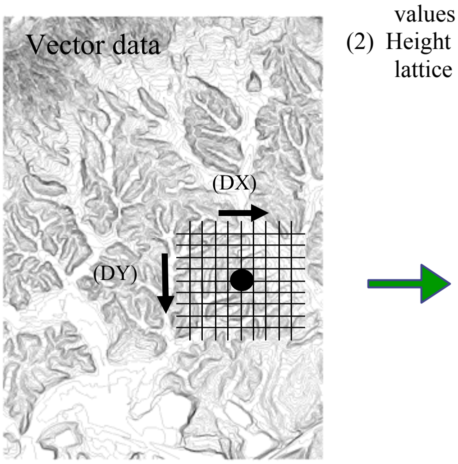
As shown in Figure 1, first, a 1/2,500 topographical map is scanned into a computer system, the raster data are made conversion to vector data, plane coordinate values are established after geometry compensation, and output to the CAD file. Next, height data are given to each contour after all the things except for the contour were deleted on CAD and a divided contour was connected. Though it is recognized as polyline, it resolves into the large number of short lines (the line that polyline was expressed by a very detailed group of straight lines) for the future DEM preparation, and the short lines are outputted to the DXF file. The height values above sea level of all positions of a lattice point in the object region are calculated with reading a DXF file by the analytical program with inside interpolating on the position of a lattice point of the specified mesh interval. On this occasion, as shown in Figure 2, inside interpolating is made in the direction where the slope with biggest angle of inclination calculated from a contour (short lines) to cross in the beginning in 8 direction from the lattice point, and the 3rd Hermite function is used for the inside interpolating function at each lattice points (PRIMA Oky Dicky A. et al. 2001).



(1) 1/2,500 topographical map is scanned into a computer system.
(2) Raster data are made conversion to vector data.
(3) Geometrical correction.
(4) Plane coordinate values are established.
(5) Output to the CAD file.
(6) Unnecessary things deletion, contour modification, connection.
(7) Height above sea level values input.
(8) Polylines are changed to short lines
(9) Output to the DXF file.

Figure 1 Creation procedure of DEM

(1) The mesh intervals are specified (DX and DY) to calculate height values at each point.
(2) Height above sea level values are interpolated at a position of a lattice point of the specified mesh interval



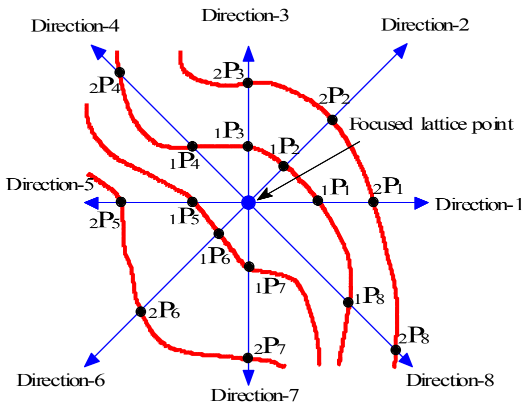


Figure 2 Interpolating of height values above sea level

3. PRECISION OF DEM AND ITS INFLUENCE FOR GEOGRAPHICAL ANALYSIS

The grid spacing of DEM which was formed from the 3-dimensional vector data are decided under considering the original scale (e.c. 1/1000,1/2500,1/3000) of the former topographical maps and the city planning maps, a contour interval (for main-line and vice-line) and the amount of generating data. Of course, precision to the resolution can be thought to become very vague, though even DEM of what kind of grid spacing can be formed if the resolution and the overfull amount of data are ignored. So, precision verification is performed about DEM of with 10m grid spacing formed in this study, and the microtopography features analysis with generated DEM is examined about the influence on artificial embankment land form analysis.

As shown in Figure 3 and Figure 4, 3-D topographic map of Takamigaoka residential land site and Hiroshima university campus site are displayed by wire mesh respectively in condition of after reclaim. Though artificial embankment land slope forms can be seen here and there in each figures, the places with high embankment land slope forms are extracted and examined particularly (these extracted places are enclosed with the circle in each figures). The enclosed place with the circle was south end of continued rice paddy to north and south in condition of before reclaim, the valley of continued rice paddy (Goma valley) was filled and its south end becomes high rise artificial slope in front of the balancing reservoir at the present day. Figure 5 shows the state of filling up the valley three-dimensionally using the DEM which are generated by the city planning map of Takamigaoka residential land site before and after reclaim. As shown in Figure 6, the position of the

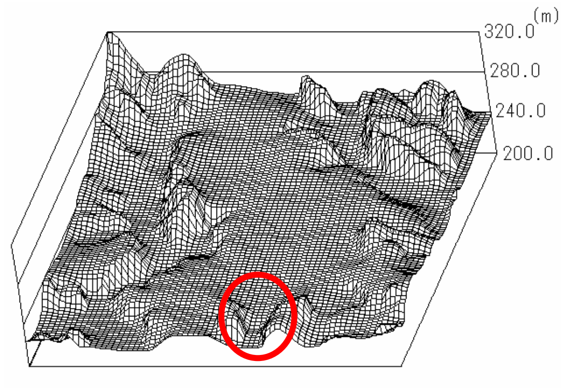


Figure 3 3-D topographic map of Takamigaoka residential land site

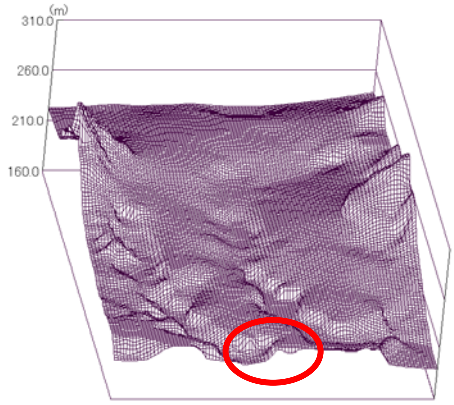


Figure 4 3-D topographic map of Hiroshima university campus site

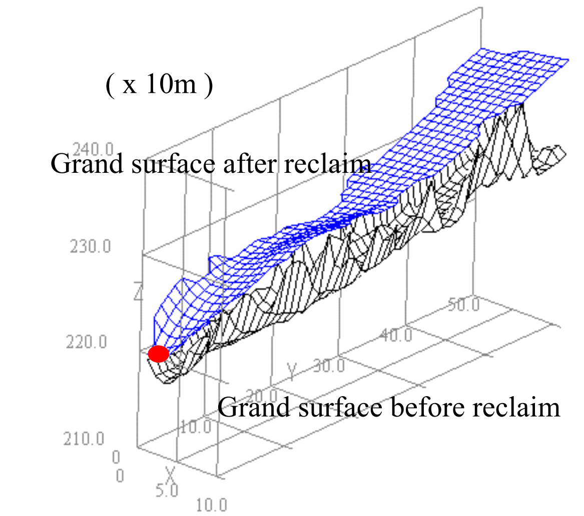


Figure 5 Extracted example of banking valley area in Takamigaoka residential land

Figure 7 Site of Takamigaoka residential land in 2006 house map

valley of continued rice paddy (Goma valley) is surrounded by the red dotted line frame in the old Higashi-Hiroshima City planning map (1/2500) in 1973. The blue dotted line frames show the filled area of the valley of continued rice paddy (such as Joufuku-ji valley) in the same figure, these area has a high rise artificial slope in that south end front, too. In Figure 5, though the slope at the end of the south could be confirmed, the balancing reservoir (see Figure 7) at that back couldn't be confirmed and it is very different from slope height by the field surveying and a slope as shown in the table 1. In other words, it becomes an average on the height above sea level value and it can think that it is shown as a more gentle slope because the preparation interval of DEM was made wide under considering the precision of the contour of the original maps.

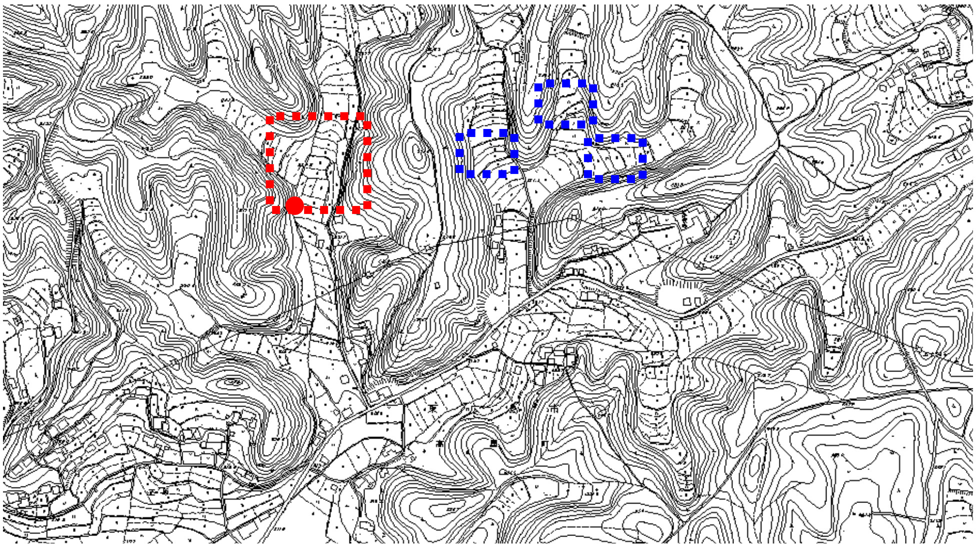


Figure 6 Recasting slope area before reclaim
(planned site of Takamigaoka residential land: 1973)

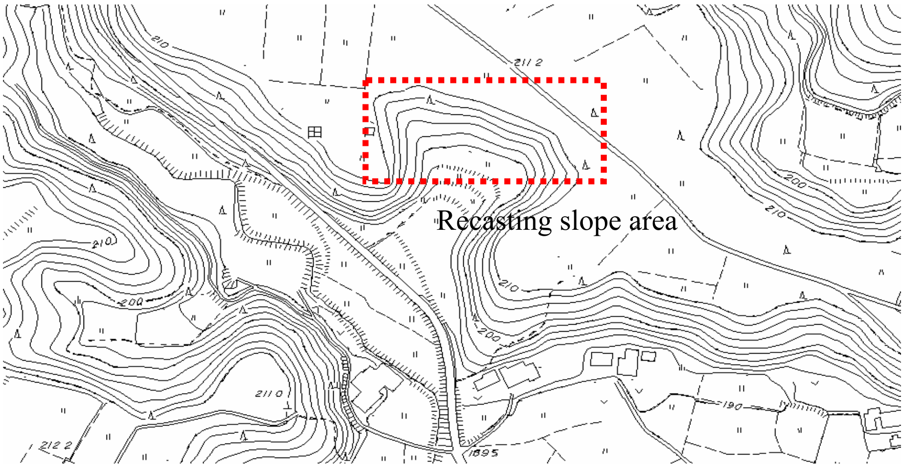


Figure 8 Recasting slope area before reclaim
(planned site of Hiroshima university campus: 1973)

On the other hand, there were rice paddies in a position of a red circle in Hiroshima university campus site before the development as shown Figure 4, and it seems that small-scale irrigation pond existed here and there in the neighbor area, too (see Figure 8). And, this point is the south end of Hiroshima university campus site with high rise artificial slope which large-scale slope collapse occurred in 2001 Geiyo Earthquake. (see Figure 9 and Figure 10). The three-dimensional forms of the slope made from DEM before and after the development are shown in Figure 11 and Figure 12 respectively. The field investigations are compared with the height and the inclination of this artificial slope which were estimated by DEM before and after the development as shown in Table 2. As for the scale of the artificial slope geographical features formed from DEM before and after the development, it is understood that it is an underestimate very much even in this point. It becomes an average on the height above sea level value and it can think that it is shown as a more gentle slope because the preparation interval of DEM was made wide under considering the precision of the contour of the original maps as well as the case of artificial slope at the Takamigaoka residential land site.

Table 1 Comparison of the estimated slope dimensions (Recasting slope in Takamigaoka residential land)

	Slope height (m)	Inclination (degree)
By DEM	8	15
By field survey	15	40

Table 2 Comparison of the estimated slope dimensions (Recasting slope in campus of Hiroshima University)

	Slope height (m)	Inclination (degree)
By DEM	9	28
By field survey	17	40

Figure 9 Slope failure due to 2001 Geiyo Earthquake shock

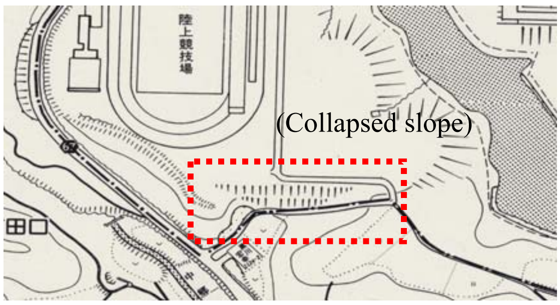


Figure 10 Location of the collapsed slope in 2006 house map

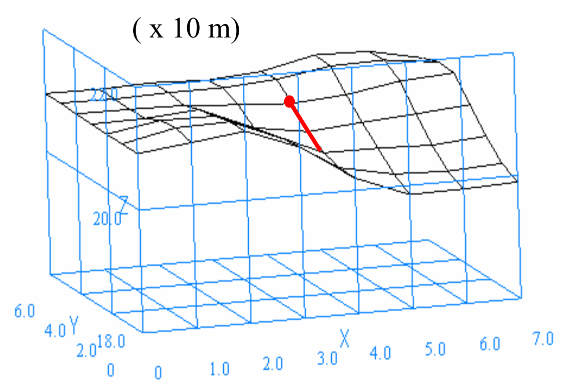


Figure 11 3-D slope land from by DEM before reclaim

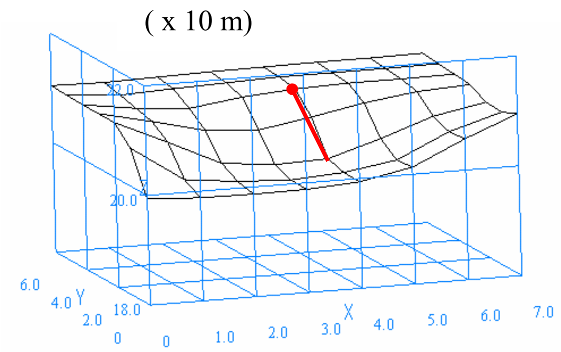


Figure 12 3-D slope land from by DEM after reclaim

4. SLOPE STABILITY ANALYSIS

In this study, slope stability analyses are performed based on DEM before/after the development and field surveying, and those results are compared mutually furthermore. The slope stability analysis is as a plane problem of the slope cross-section for the simplification, and a straight slide line is assumed (see Figure 13 and Figure 14). The slope inclination: θ (in the Eqn.4.1) of the straight slide line is derived from the rotation angle: δ (in the Eqn.4.2) in main stress direction in consideration of the horizontal and vertical external force by the earthquake (see Figure 15 and Figure 16).

$$\theta = \frac{\pi}{4} + \frac{\phi}{2} - \delta \tag{4.1}$$

$$\tan 2\delta = \frac{2\tau}{\sigma_v - \sigma_h} = \frac{2k_h \gamma Z}{\gamma Z(1-k_v) - K\gamma Z(1-k_v)} = \frac{2k_h}{(1-K)(1-k_v)} \tag{4.2}$$

where, K: earth pressure coefficient, k_h: horizontal seismic intensity, k_v: vertical seismic intensity and γ: specific weight of the soil.

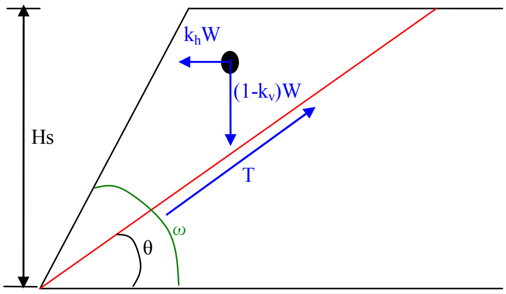


Figure 13 Plane slip failure model

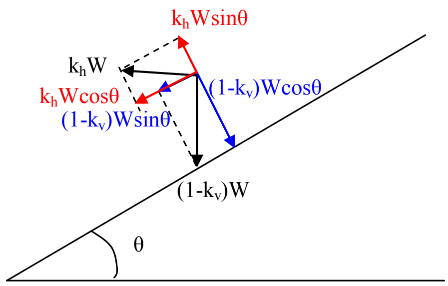


Figure 14 Equilibrium of force on slip surface

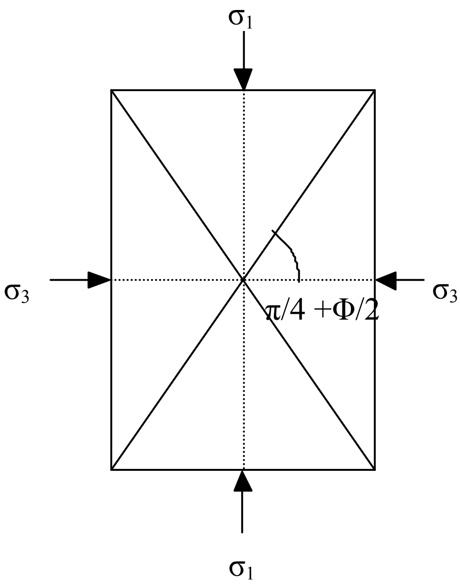


Figure 15 Direction of Slip line to horizontal direction

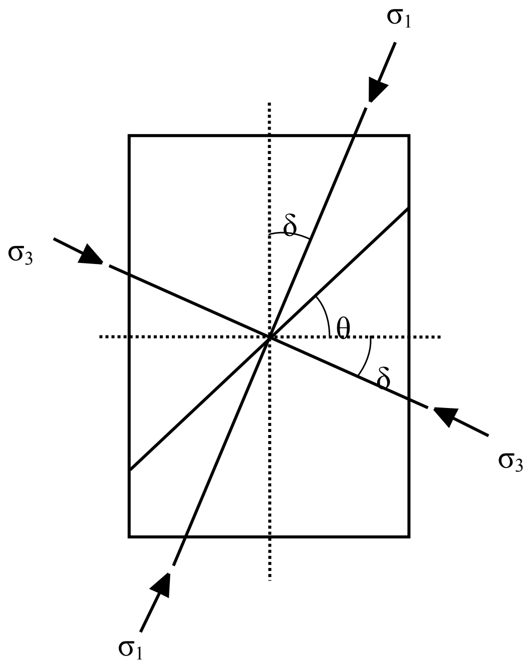


Figure 16 Rotation angle of principal stress axis: δ and direction angle of slip line: θ

The safety factor Fs for the slope stability is derived from Eqn.4.3 and Eqn.4.4 with reference to these analytic models.

$$T = cl + \{(1 - k_v)W\cos\theta - k_h W\sin\theta\}\tan\phi \qquad (4.3)$$

$$S = (1 - k_v)W\sin\theta + k_h W\cos\theta \qquad (4.4)$$

$$Fs = T / S \qquad (4.5)$$

where, W: weight of the sliding mass, φ: internal friction angle, c: adhesion, l: the length of the slide line.

As shown Figure 17, safety factors Fs to the horizontal seismic intensity k_h in the slope cross-section direction (north and south direction) are compared. The strength constants of soil (φ= 35°, c=5. 9KN/ m^2) and the unit weight (γ=19. 9.6KN/m^3) were decided from the soil tests, and the maximum horizontal seismic intensity k_h at this point was estimated as 0.20-0.26 in the north and south direction of the Geiyo earthquake in 2001 by Hiroshima Prefectural network of seismic stations. Though it is judged a very safe slope from a result of a calculation by DEM, Fs is less or equal 1.0 in part of horizontal seismic intensity k_h which is greater or equal 0.3 based on the slope form data by the field surveying. This result near consist with the estimated maximum horizontal seismic intensity k_h=0.2-0.26.

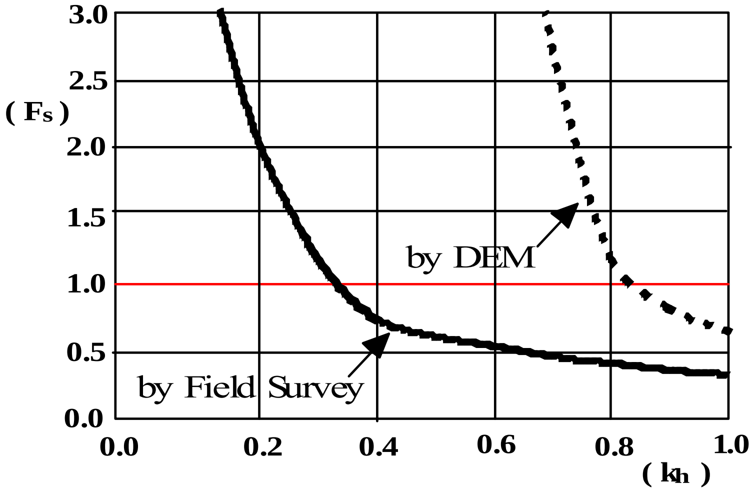


Figure 17 Results of seismic stability analysis for slope

5. CONCLUDING REMARKS

As the DEM has an average on the height above sea level values and the inclination of slope by DEM is more gently than actual one, the results of the stability analysis based on DEM are very different from the actual results based on the field surveying. However, it is very difficult because enormous labor and expenses are required to make detailed DEM for precision which to be better. Therefore, we must analyze it based on the detailed surveying data in each point after the artificial embankment land form are extracted from the viewpoint concerning a wide area by using DEM which can distinguish a geographical features form, cut/bank height, and so on to a certain extent. On the other hand, it is likely to be scattered and lost because most information were existed in the geographical features information before the development only on the paper map. So, we must collect the old geographical features information on the paper map systematically immediately and digitize it.

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