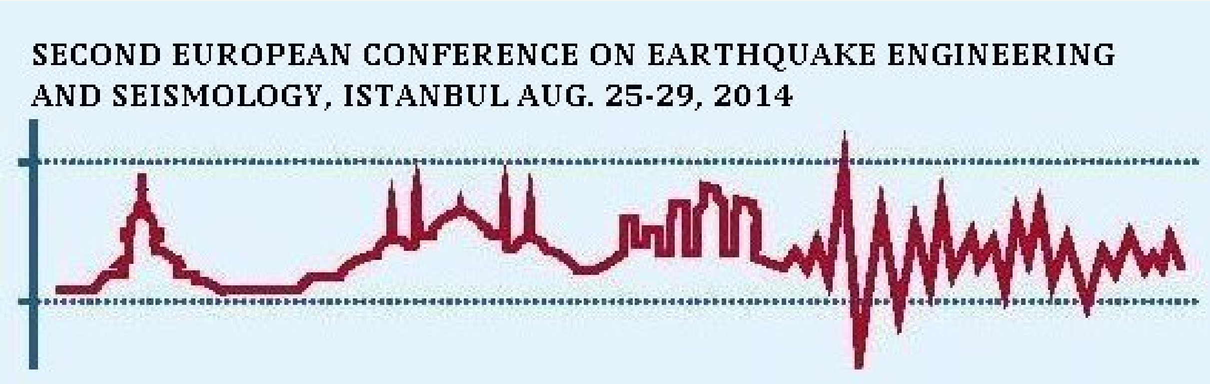

SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING
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A NEW DETERMINATION OF FORBIDDEN DISTANCE FOR HOUSE CONSTRUCTION DUE TO A LARGE-SCALE EARTHQUAKE

Shoko KOMAI[1], Yoshiya HATA[2] and Ken-ichi TOKIDA[3]

INTRODUCTION

Banking and cutting slopes are often used in the construction of infrastructure such as residential houses, expressways, railroads and airports. Damage to slopes has been reported frequently as a result of the major earthquakes that have occurred in recent years in Japan. For instance, a lot of residential fill slopes failed in the 2011 off the Pacific coast of Tohoku Earthquake.

The indices used for earthquake resistance assessment of banking and cutting slopes are safety factor (e.g. JRA, 2010), sliding displacement (e.g. Newmark, 1965), residual displacement (e.g. Wakai and Ugai, 2004) and travelling displacement (e.g., Tochigi et al., 2009) (see Fig.1). The range of anticipated slope failure is not taken into consideration in the seismic guidelines for banking and cutting slopes in Japan (JRA, 2010; NEXCO 2009; JGS, 2007; RTRI, 2007; SCOPE, 2008). However, in addition to these considerations, evaluation based on the slope failure range is very important from the viewpoint of the remaining function and recoverability of the actual facilities (e.g., Hata et al. 2012a). For instance, a case of residential fill slope, if the range of the slope failure is small, residential function may be partially maintained. If the size of the slope failure is large, residential function may be significantly restricted. Especially, in this content, the failure range on the crest (Definition: the horizontal distance from the slope crest to the slip surface) is very important.

In this study, based on the above-mentioned background, we focused on the following 7 residential fill slopes (see Fig.2). Failure range of these slopes reached to the foundation of the houses by the past large earthquakes. The 7 previously mentioned case histories are shown below.

1. [Asahidai Case] A slope failure due to the 2011 off the Pacific coast of Tohoku Earthquake at Asahidai, Fukushima City, Fukushima Prefecture (e.g. Hata et al. 2012b; Komai et al. 2013a).
2. [Seikaen Case] A slope failure due to the 2011 off the Pacific coast of Tohoku Earthquake at Seikaen, Aoba Ward, Sendai City, Miyagi Prefecture (e.g. Hata et al. 2013a).
3. [Taiyo New Town Case] A slope failure due to the 2011 off the Pacific coast of Tohoku Earthquake at Taiyo New Town, Yamamoto Town, Miyagi Prefecture (e.g. Hata et al. 2013b, Komai et al. 2013b).
4. [Tate New Town Case] A slope failure due to the 2011 off the Pacific coast of Tohoku Earthquake at Tate New Town, Ichinoseki City, Iwate Prefecture (e.g. Hata et al. 2014; Komai et al. 2013c).
5. [Takamachi Case] A slope failure due to the 2004 Mid Niigata Prefecture Earthquake at Takamachi, Nagaoka City, Niigata Prefecture (e.g. Komai et al. 2013d)
6. [Ryojo Case] A slope failure due to the 2001 Geiyo Earthquake at Ryojo, Kure City, Hiroshima Prefecture (e.g. Hata et al. 2013c, Komai et al. 2013e).

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[1] Graduate Student, Graduate School of Engineering, Osaka University, skomai@civil.eng.osaka-u.ac.jp
[2] Assistant Professor, Graduate School of Engineering, Osaka University, hata@civil.eng.osaka-u.ac.jp
[3] Professor, Graduate School of Engineering, Osaka University, tokida@civil.eng.osaka-u.ac.jp

7. [Midorigaoka Case] A slope failure due to the 1993 off Kushiro Earthquake at Midorigaoka, Kushiro City, Hokkaido Prefecture (e.g. Hata et al. 2013d).

ORDINANCE CONCERNING CLIFF IN JAPAN WITH FORBIDDEN DISTANCE FOR HOUSE CONSTRUCTION

On the other hand, Prefectural Ordinance for Enforcement of the Building Standards Act has

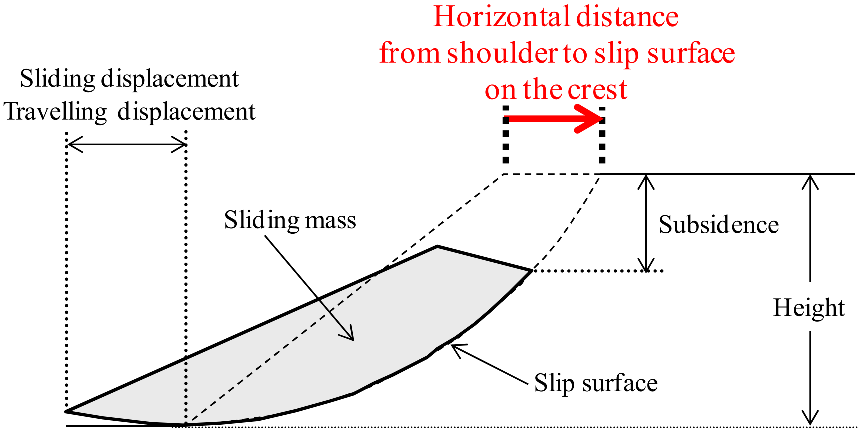

Figure 1. The importance of evaluation of slope failure range

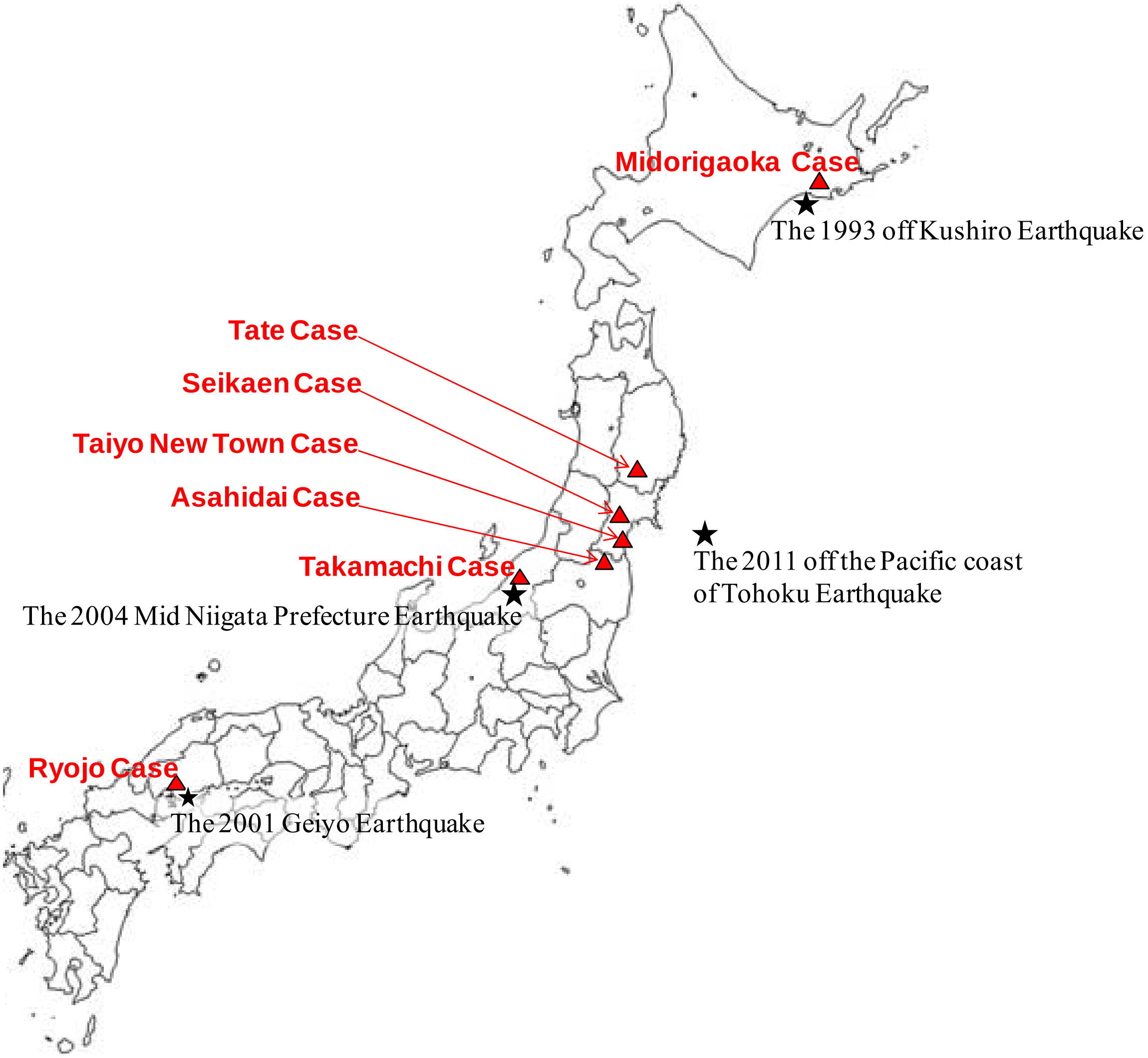

Figure 2. Location of the 7 previously mentioned case histories

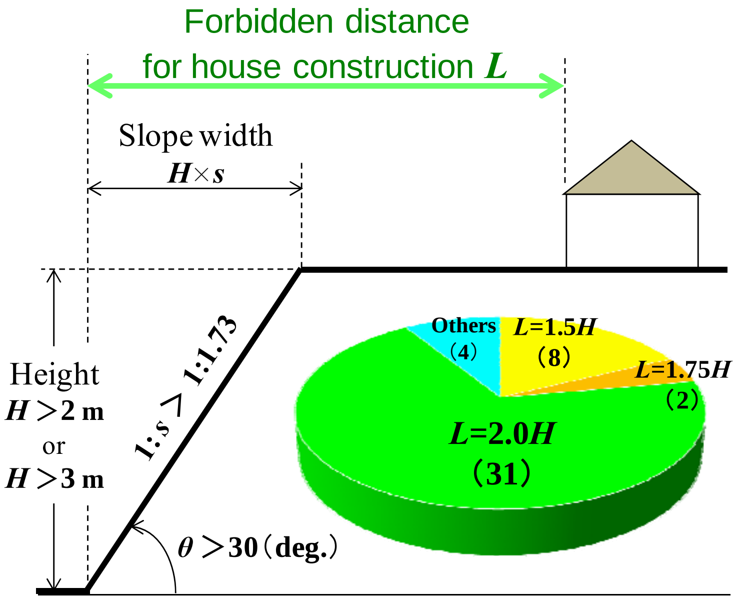

Figure 3. Present tendency of Ordinance Concerning Cliff in Japan with forbidden distance for house construction

regulations on forbidden distance for house construction close to a slope (e.g., Hirade and Tamura, 2006). In Japan, we call this enforcement 'Ordinance Concerning Cliff'. The cliff ordinance is various by each 45 prefectures except Osaka and Nagano Prefectures. Fig.3 arranged the contents of Ordinance Concerning Cliff of 45 prefectures. The most popular Ordinance Concerning Cliff at a slope of interest is defined by the following equation.

$$L=2.0\times H \tag{1}$$

Where, L is horizontal distance from toe of the slope crest to slip surface on the crest and H is slope height which means vertical distance from toe to shoulder of the slope (see Fig. 3). The guideline by the equation (1) is adopted in Fukushima (Asahidai Case), Miyagi (Seikaen Case and Taiyo New Town Case), Iwate (Tate New Town Case), Niigata (Takamachi Case) and Hokkaido (Midorigaoka Case) Prefectures. The other Ordinance Concerning Cliff in Hiroshima Prefecture is restricted the forbidden distance for house construction by the following equation.

$$L=1.7\times H \tag{2}$$

However, in the 7 previously mentioned case histories, the slope failures reached to the foundation of the houses. In Equations (1) and (2), a residential fill slope with not only the slope height of more than 3 m but also slope gradient of more than 1:1.73 is an application of Ordinance Concerning Cliff. Here, Midorigaoka Case and Ryojo Case have a slope where Ordinance Concerning Cliff is applied. That is, in these cases, some houses were constructed before the past large-scale earthquakes by satisfying each Ordinance Concerning Cliff (each regulation distance L). On the other hand, Takamachi Case, Seikaen Case, Asahidai Case, Taiyo New Town Case and Tate New Town Case are without regulations of Ordinance Concerning Cliff. This is because the slope gradient is less than 1:1.7 in these 5 cases. Therefore, the 7 case histories have suggested that the proposal of a new regulation determination is required regardless of the application conditions of the present Ordinance Concerning Cliff.

EXAMPLE OF EVALUATION OF SLOPE FAILURE RANGE

In this study, a method to estimate the failure range of an embankment is proposed. The proposed method was applied for the 7 previously mentioned case histories. In this chapter, we introduce the evaluation result of the slope failure range in Asahidai Case as an example case.

The residential fill slope of interest at Asahidai, Fukushima City, Fukushima Prefecture was failed in the 2011 off the Pacific coast of Tohoku Earthquake. The serious damage such as intercepting

Phototograph 1. Damage condition at the slope site of interest based on the author's reconnaissance results

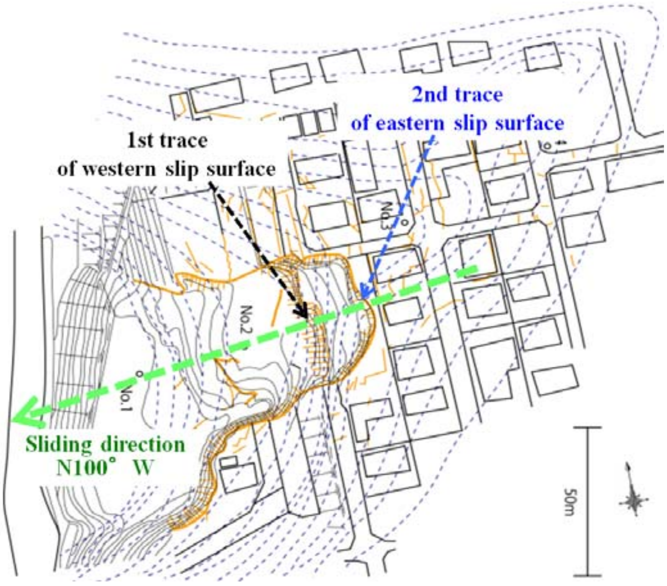

Figure 4. Bird's-eye view with the damage condition of the slope failure

traffic of National Highway No.4 occurred in travelling displacement by slope failure of the residential fill bank due to the 2011 main shock (Nakamura et al. 2012).

A bird's-eye view with the condition of slope failure is shown in Fig. 4. Here, we have also added the main landslide direction (N100°W) to Fig. 4. Furthermore, Fig. 5 shows two-dimensional model of the slope of interest in the N100°W direction. In Fig.5, the height is 30 m and the gradient is 1:1.7 and 1:2.0, the slope of interest is without regulation of Ordinance Concerning Cliff in Fukushima Prefecture. However, the failure range from toe of the slope is 70.2 m (Trace of western slip surface) and 85.9 m (Trace of eastern slip surface). Moreover, the slope failure range reached to the foundation of the houses, and serious damage of some houses collapsing occurred (see Photograph 1).

Fig. 6 shows the result of stability analysis for the slope of interest. The process of estimating the slope failure range consists of the following 3 simple steps. First, we investigate a critical slide circle to a residential fill slope based on the modified Fellenius Method (Fellenius, 1936). Here, applying the empirical equation (Noda et al. 1975) to the peak ground acceleration of a presumed earthquake motion at the slope site of interest (Hata et al., 2012b) estimated the horizontal seismic coefficient k_H. Next, we remove the sliding soil block by the critical slide circle from the above-mentioned initial slope model. We call this process the slope failure range by "Firstly Slip". Finally, based on the slope model which removed the sliding soil block by Firstly Slip, we also investigated the critical slide circle using the modified Fellenius Method without the horizontal seismic coefficient (k_H=0.0). We call this process the slope failure range by "Secondly Slip". We defined horizontal distance from toe of the slope to not only Firstly Slip but also Secondly Slip on the crest as the slope failure range in this study.

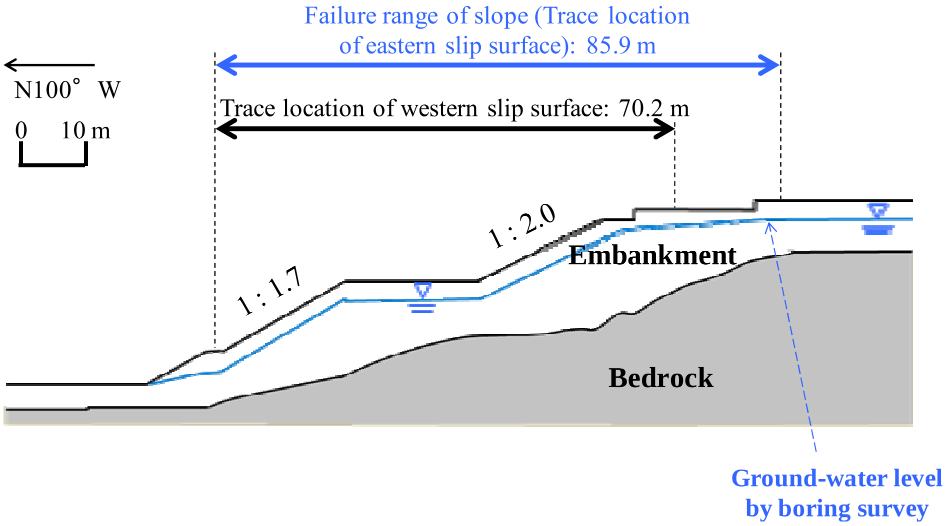

Figure 5. Two-dimensional model of the slope of interest

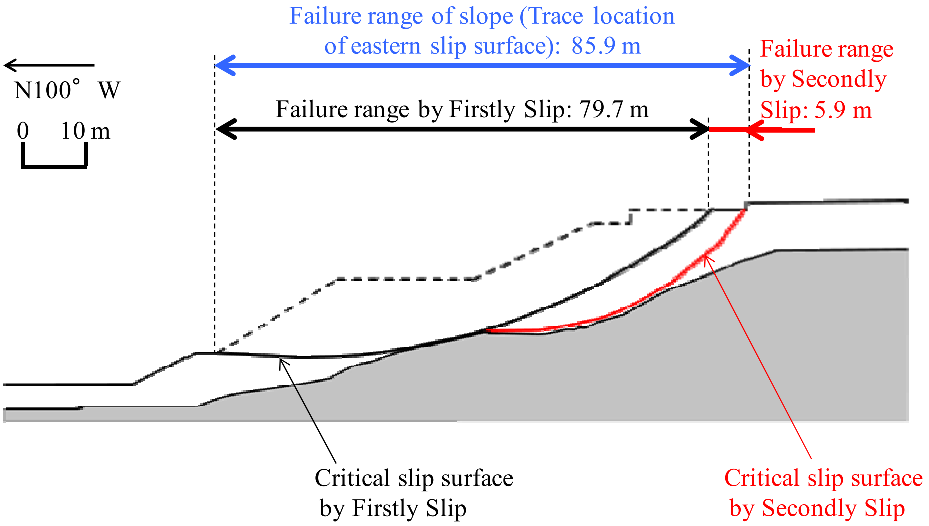

Figure 6. The results of failure range in the slope of interest

In Asahidai Case, the horizontal seismic coefficient k_H is 0.292. Moreover, in this fill slope, the unit weight γ is 16.87 kN/m^3 based on the previous study (Ono and Nakamura, 2013), and the cohesion c is 29 kPa, internal frictional angle ϕ is 14.8 deg based on the result of CD test (Nakamura et al., 2012). The groundwater level (see Fig. 5) was based on the past ground investigation test at the site of interest (Nakamura et al., 2012) .

In Fig.6, the estimated slope failure range is 79.7 m considering “Firstly Slip”. The estimated range is not similar with the observed slope failure range of 85.9 m. However, as shown in Fig. 4, we can observe the trace of the slope failure at not only the west side but the east side. In addition, we carried out the hearing to some residents who lived near the slope of interest. As the hearing results, they said that the failure range had not reached to the foundation of the houses immediately after the 2011 main shock. We have confirmed that the above-mentioned results coincidence with the actual results based on the resident hearing.

In this study, therefore, we carried out slope stability analysis considering “Secondly Slip”. In Fig.6, the observed slope failure range is 85.9 m, the estimated slope failure range considering not only “Firstly Slip” but also “Secondly Slip” is 85.6 m (=79.7 m＋5.9 m). The difference between the observed range and the estimated range is very small. It suggests that application for the proposed method to estimate the failure range of an embankment in this study is high comparatively.

FINDINGS ON ESTIMATION OF SLOPE FAILURE RANGE

We have also carried out analysis of the slope failure range about the remaining 6 cases except the above-mentioned Asahidai Case. The list of the estimation results of the slope failure ranges based on the results of existing study (e.g. Hata et al. 2012b; Komai et al. 2013a, Hata et al. 2013a, Hata et al. 2013b, Komai et al. 2013b, Hata et al. 2014; Komai et al. 2013c, Komai et al. 2013d, Hata et al. 2013c, Komai et al. 2013e, Hata et al. 2013d) is shown in Table 1.

In Table 1, as a result, in all 7 slopes of interest, the evaluation method of the slope failure range considering not only "Firstly Slip" but also "Secondly Slip" was able to simulate in high accuracy with maximum 10% errors (Komai et al. 2014).

In addition, Table 1 also shows a quasi-estimation result of slope failure range considering "Thirdly Slip" in all 7 slopes of interest. Here, the failure range due to "Thirdly Slip" is based on all of the failure range from "Firstly Slip" via "Secondly Slip" to "Thirdly Slip", is also obtained from investigation result of critical slide circle based on the slope model which removed the sliding

Table 1. List of the examination results of the 7 previously mentioned case histories

Index	**Asahidai Case**	**Seikaen Case**	**Taiyo New Town Case**	**Tate New Town Case**	**Takamachi Case**	**Ryojo Case**	**Midorigaoka Case**
Damaged Earthquake	The 2011 Tohoku EQ.				The 2004 Mid Niigata Pref. EQ.	The 2001 Geiyo EQ.	The 1993 off Kushiro EQ.
Damage site	Asahidai, Fukushima City	Seikaen, Sendai City	Taiyo New Town, Yamamoto Town	Tate New Town, Ichinoseki City	Takamachi, Nagaoka City	Ryojo, Kure City	Midorigaoka, Kushiro City
Slope height (m)	30	44	15.8	9.4	8.2	3.8	12.6
Gradient of slope 1:s	1 : 1.7 1 : 2.0	1 : 2.1	1 : 4.3 1 : 3.2	1 : 2.1	1 : 3.2	1 : 0.68	1 : 1.62
Application of Ordinance Concerning Cliff (OCC)	No	No	No	No	No	Yes	Yes
Regulation distance of OCC (m)	—	—	—	—	—	3.86	4.79
Unit Weight (kN/m^3)	16.9	17.5	18.9	14.9	16.2 & 18.4	18.8	15.3
Cohesion c (kPa)	29.0	14.0	9.0	0.0	0.0	25.4	14.7
Friction angle ϕ (deg.)	14.8	32.0	31.7	39.0	36.9	28.5	15.0
Earthquake type	subduction-zone				Crustal	Intraslab	
PGA due to main shock (Gal)	656	676	591	452	635	605	279
Effect of aftershock	No				Yes	No	
PGA due to aftershock (Gal)	—	—	—	—	503	—	—
Observed failure range R (m)	**85.9**	**7.3**	**8.8**	**7.7**	**26.7**	**5.2**	**9.8**
R/H	2.86	0.17	0.56	0.82	3.26	1.37	0.78
Seismic coefficient due to main shock	0.292	0.295	0.282	0.258	0.288	0.284	0.219
Estimated failure range (Firstly Slip) E_1 (m)	79.7	3.9	3.6	1.5	16.4	3.4	6.5
Estimation accuracy (Firstly Slip) E_1/R	0.93	0.53	0.41	0.19	0.61	0.65	0.66
Seismic coefficient due to aftershock	0.0				0.0 or 0.267	0.0	
Estimated failure range (Secondly Slip) E_2 (m)	**85.6**	**7.1**	**8.8**	**8.0**	**22.9 or 29.8**	**5.7**	**9.8**
Estimation accuracy (Secondly Slip)E_2/R	**1.00**	**0.97**	**1.00**	**1.04**	**0.86 or 1.12**	**1.10**	**1.00**
Seismic coefficient due to aftershock	0.0						
Estimated failure range (Secondly Slip) E_3 (m)	89.2	10.5	10.8	11.0	33.4	8.3	18.5
Estimation accuracy (Secondly Slip)E_3/R	1.04	1.44	1.23	1.43	1.25	1.60	1.89

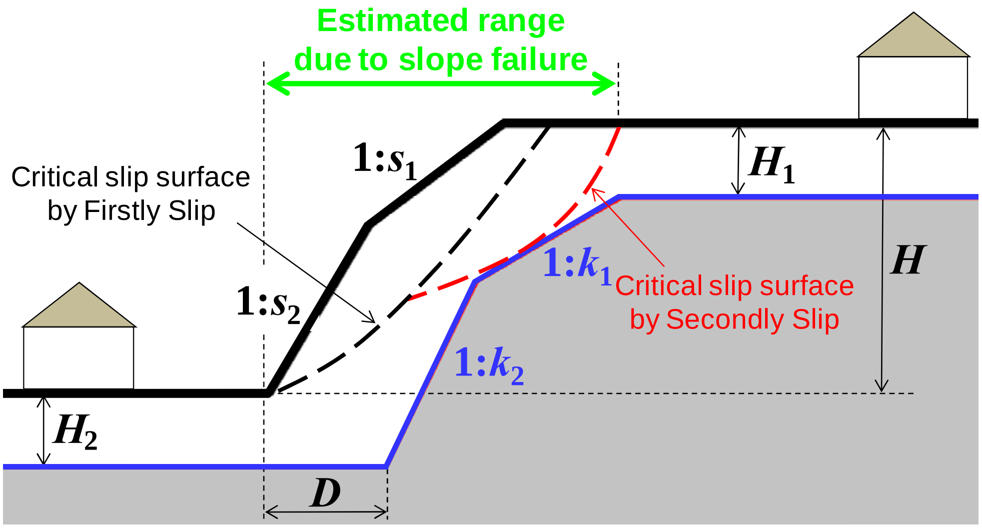

Figure 7. Some parameters which were expected to have an influence on failure range of slopes

soil block by "Secondly Slip" without the horizontal seismic coefficient (k_H=0.0). In all the examination cases, the failure range due to "Secondly Slip" has a difference smaller than the failure range due to "Thirdly Slip" with the observed slope failure range. It suggests that a possibility that an actual range of slope failure will reach to near the estimated range of the slope failure due to "Secondly Slip". Based on the above-mentioned findings, in predicting failure range of a residential fill slope during a future large-scale earthquake, we think that the necessity of taking into consideration not only the effect of "Firstly Slip" but the effect of "Secondly Slip".

Therefore, as a 2nd stage, we proposed the new estimation and regulation equation concerning the slope failure range of a residential fill slope due to a large-scale earthquake. The proposal process consists of the following 3 chapters.

SENSIBILITY ANALYSIS

Based on the findings obtained from the result of analysis of the 7 previously mentioned case histories, we examined the determination of the numerical calculation condition. First, as some parameters which were expected to have an influence on failure range of slope, as shown in Fig. 7, we choose 11 parameters (Slope height H, ground layer thickness from engineering bedrock to surface H_1, H_2, the horizontal shortest distance between embankment and inclined bedrock D, gradient of embankment slope 1:s (s_1:top, s_2:bottom), gradient of inclined bedrock 1:k (k_1:top, k_2:bottom), unit weight of embankment γ (kN/m^3), cohesion of embankment c, internal frictional angle of embankment ϕ, and horizontal seismic coefficient k_H (k_{H1}: "Firstly Slip", k_{H2}: "Secondly Slip").

Then, we analyzed sensitivity to select the parameters which had influence to slope failure range in 11 parameters. Table 2 shows the list of value for the sensitivity analysis. The range of fluctuation of the value was determined based on the 7 previously mentioned case histories. In particular, fundamental slope model was determined based on the combination of the median value (see value based on white color with gray hatching in Table 2). We changed only one kind of parameter gradually in the fundamental slope model, in order to select the parameter which has large influence on the slope failure range. In addition, we neglected change of the gradient in not only embankment slope but also inclined bedrock. That is, we determined that same gradient of s_1=s_2 and k_1=k_2. Moreover, we determined two patterns about the horizontal seismic coefficient k_H during the estimation of slope failure range due to "Secondly Slip". In particular, one is with consideration of the effect of aftershock (k_{H1}=k_{H2}), and the other is without the effect of aftershock (k_{H2}=0.0) .

Finally, we carried out the evaluation of failure range of slopes for all 48 cases. The evaluation method for the slope failure range is investigating critical slide circle for not only Firstly Slip but also Secondly Slip. The result of the sensitivity analysis on the reference of the most popular Ordinance Concerning Cliff by Equation (1) is shown in Fig. 8. In Fig. 8, the selected parameters to have a large influence on the slope failure range are the slope height H and the slope gradient 1:s. In the parametric study of next chapter, therefore, we adopted the range of fluctuation of three parameters which consist of the slope height H_0, the gradient of embankment slope 1:s and the gradient of inclined bedrock 1:k, considering the relationship between the gradient of embankment slope 1:s and the gradient of inclined bedrock 1:k.

Table 2. List of the determined value for the sensitivity analysis and parametric study

<table>
<tr><td>H_0 (m)</td><td colspan="5">3</td><td colspan="5">10</td><td colspan="5">17</td><td colspan="5">24</td><td colspan="5">31</td><td colspan="5">38</td><td colspan="5">45</td></tr>
<tr><td>H_1 (m)</td><td colspan="7">0</td><td colspan="7">2</td><td colspan="7">4</td><td colspan="7">6</td><td colspan="7">8</td></tr>
<tr><td>H_2 (m)</td><td colspan="7">0</td><td colspan="7">2</td><td colspan="7">4</td><td colspan="7">6</td><td colspan="7">8</td></tr>
<tr><td>s_1</td><td colspan="5">0.7</td><td colspan="5">1.1</td><td colspan="5">1.6</td><td colspan="5">2.0</td><td colspan="5">2.7</td><td colspan="5">3.3</td><td colspan="5">4.0</td></tr>
<tr><td>s_2</td><td colspan="5">0.7</td><td colspan="5">1.1</td><td colspan="5">1.6</td><td colspan="5">2.0</td><td colspan="5">2.7</td><td colspan="5">3.3</td><td colspan="5">4.0</td></tr>
<tr><td>k_1</td><td colspan="5">0.0</td><td colspan="5">1.7</td><td colspan="5">3.4</td><td colspan="5">5.0</td><td colspan="5">5.5</td><td colspan="5">6.0</td><td colspan="5">6.5</td></tr>
<tr><td>k_2</td><td colspan="5">0.0</td><td colspan="5">1.7</td><td colspan="5">3.4</td><td colspan="5">5.0</td><td colspan="5">5.5</td><td colspan="5">6.0</td><td colspan="5">6.5</td></tr>
<tr><td>D (m)</td><td colspan="5">-4.0</td><td colspan="5">-2.6</td><td colspan="5">-1.3</td><td colspan="5">0.0</td><td colspan="5">4.0</td><td colspan="5">8.0</td><td colspan="5">12.0</td></tr>
<tr><td>γ (kN/m^3)</td><td colspan="7">15</td><td colspan="7">16</td><td colspan="7">17</td><td colspan="7">18</td><td colspan="7">19</td></tr>
<tr><td>c (kPa)</td><td colspan="7">0.0</td><td colspan="7">7.5</td><td colspan="7">15.0</td><td colspan="7">22.5</td><td colspan="7">30.0</td></tr>
<tr><td>ϕ (deg.)</td><td colspan="7">14.0</td><td colspan="7">20.5</td><td colspan="7">27.0</td><td colspan="7">33.5</td><td colspan="7">40.0</td></tr>
<tr><td>k_{H1}</td><td colspan="7">0.22</td><td colspan="7">0.25</td><td colspan="7">0.28</td><td colspan="7">0.31</td><td colspan="7">0.34</td></tr>
<tr><td>k_{H2} without aftershock</td><td colspan="35">0.00</td></tr>
<tr><td>k_{H2} with aftershock</td><td colspan="7">0.22</td><td colspan="7">0.25</td><td colspan="7">0.28</td><td colspan="7">0.31</td><td colspan="7">0.34</td></tr>
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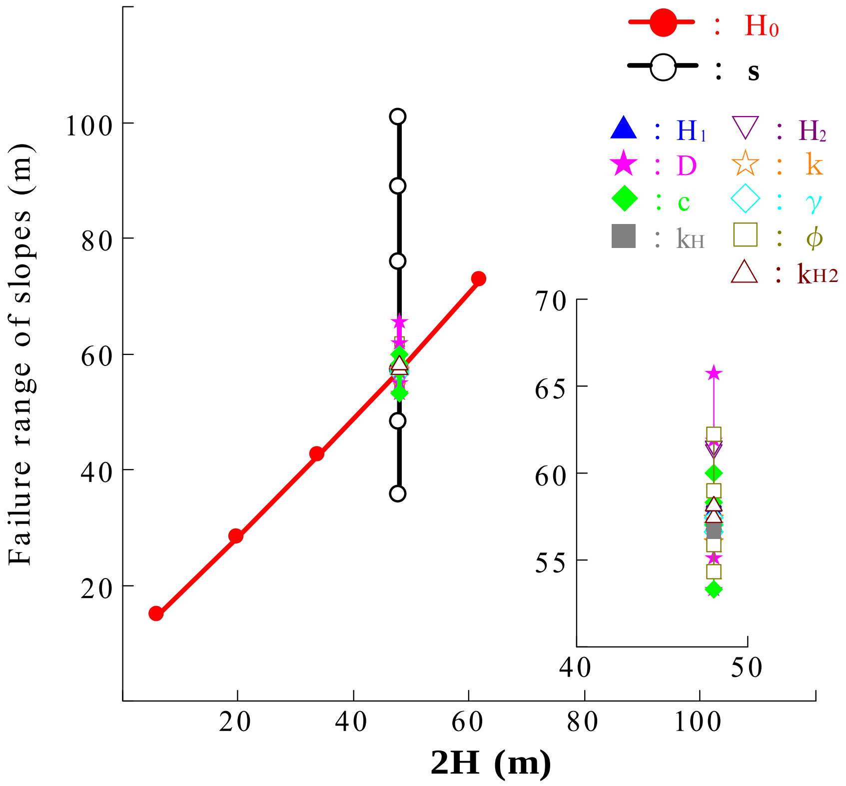

Figure 8. The results of the sensitivity analysis with the most popular Ordinance Concerning Cliff

A NEW FORBIDDEN DISTANCE FOR HOUSE CONSTRUCTION

In previous chapter, we neglected change of the gradient in not only embankment slope but also inclined bedrock (that is, $s_1=s_2$ and $k_1=k_2$). On the other hand, in this chapter, we considered the effect of the change of the gradient of embankment slope and inclined bedrock on the slope failure range (that is, $s_1 \neq s_2$ and $k_1 \neq k_2$). The estimation method of the slope failure range is same to not only the 7 previously mentioned case histories but also sensitivity analyses. As a result, we were able to obtain the estimated failure range by total 510 artificial slopes which consist of the sensibity analysis 48 cases and the parametric study 462 cases.

Figs. 9 and 10(a), (b), (c) indicates the special issue of the present Ordinance Concerning Cliff to examine relationships between the present regulation range and estimated slope failure range. In Fig. 9, the estimated failure range of the artificial slope of all 510 cases were distributed against forbidden distance for house construction by the present Ordinance Concerning Cliff (TYPE 1: Fig. 9(a), TYPE 2: Fig. 9(b), TYPE 3: Fig. 9(c), TYPE 4: Fig. 9(d)). As shown in Fig. 10, we also indicated the standard straight line which has an angle of 45 degrees (calling “45 deg. Line”).

If the estimated slope failure ranges plotted in “Safe Area” which located the bottom of “45 deg. Line”, we can confirm that the present forbidden distance for house construction was satisfied. If the estimated slope failure ranges plotted in “Dangerous Area” which located the top of “45 deg. Line”, we can confirm that the present forbidden distance for house construction was not satisfied.

In Fig. 9, in the present forbidden distance for house construction (TYPE 1-4), a lot of plots are distributed over Dangerous Area. Since the present forbidden distance for house construction (TYPE

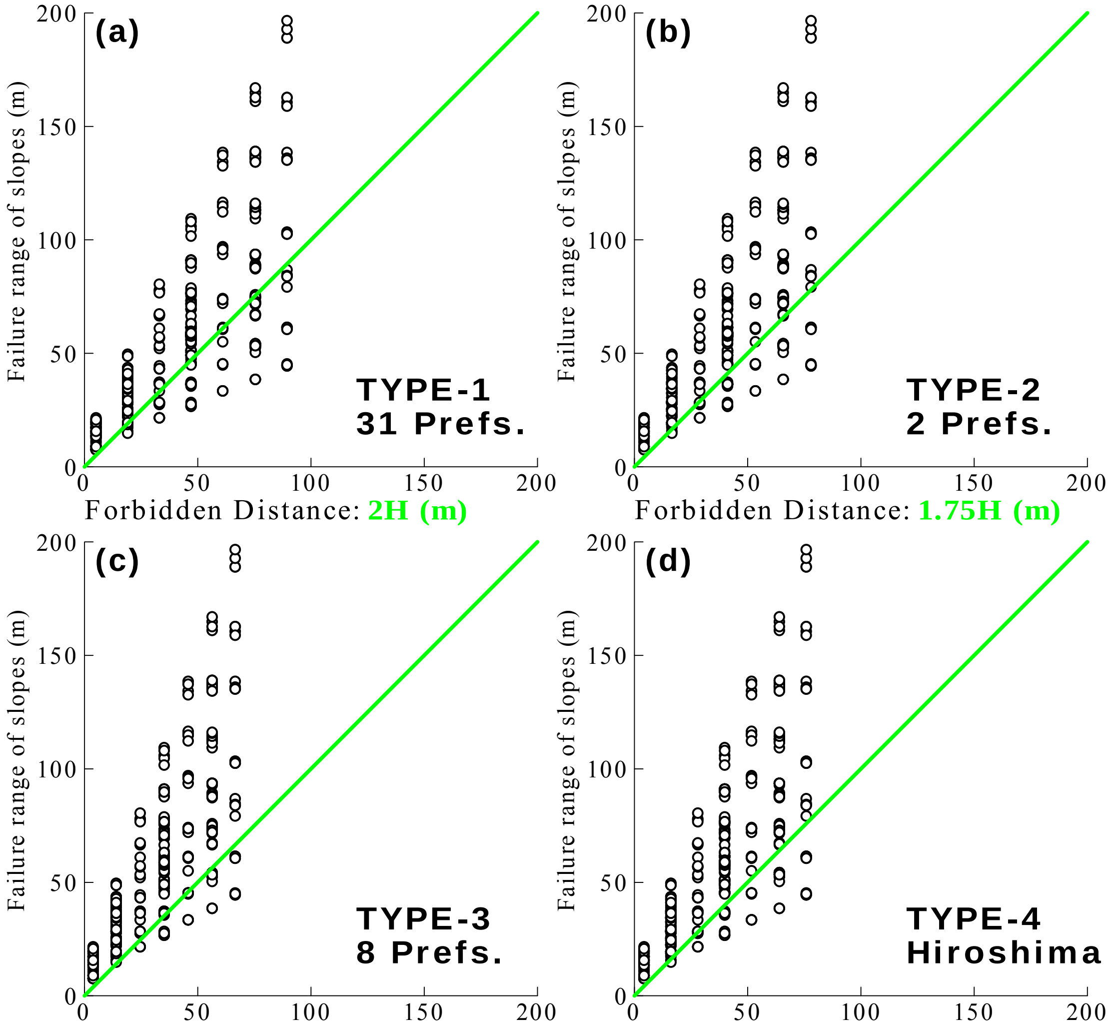

Figure 9. The estimated failure range against forbidden distance for house construction by the present Ordinance Concerning Cliff (TYPE-1~TYPE-4)

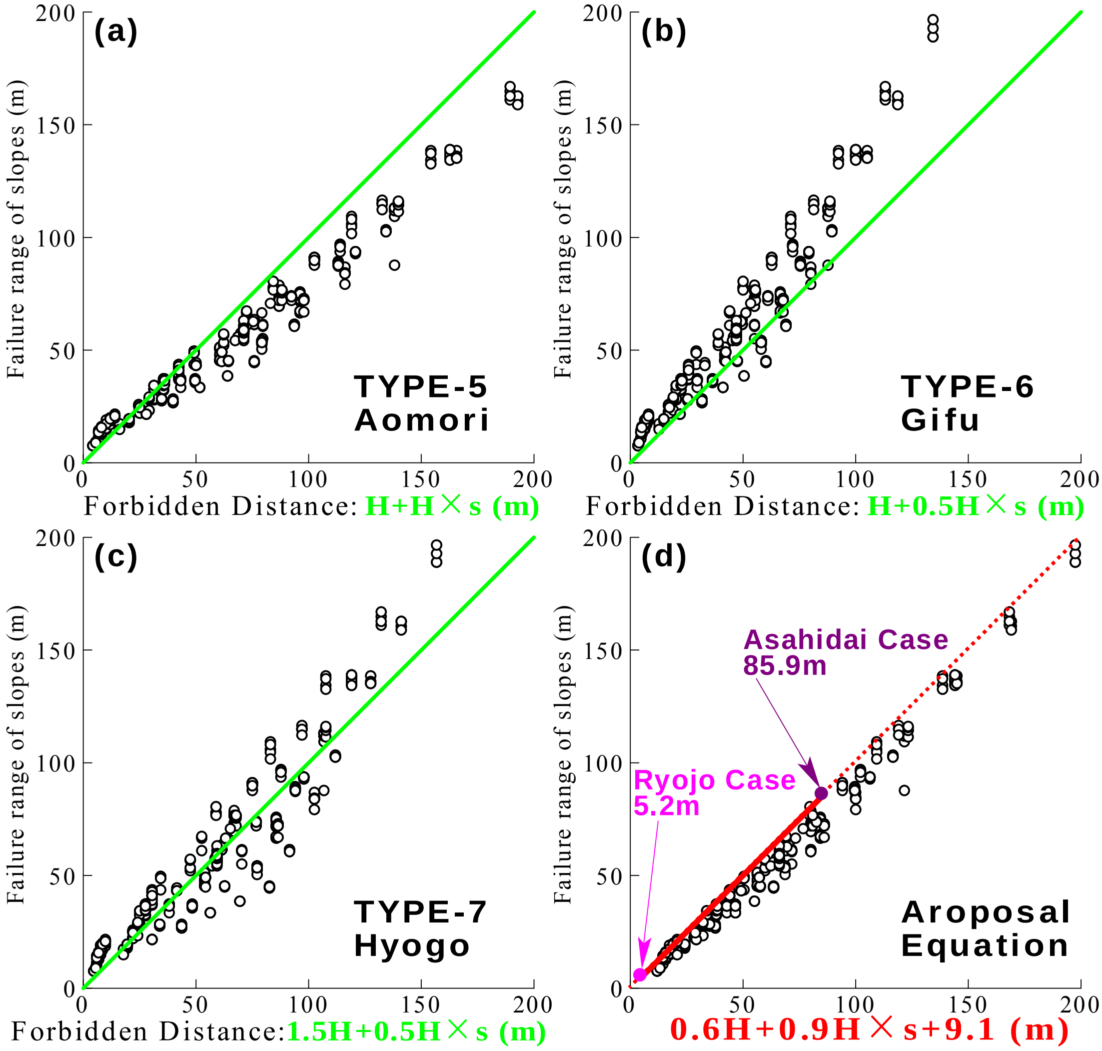

Figure 10. The estimated failure range against forbidden distance
for house construction by the present Ordinance Concerning Cliff (TYPE-5~TYPE-7),
and the proposed equation considering special issue in this study

1-4) are without the influence of gradient of embankment slope 1:*s*, it is necessary to take the influence of the gradient into consideration in the estimation equation for the failure range.

Fig. 10(a), (b), (c) indicates the distribution of the estimated failure range of the artificial slope of all 510 cases against forbidden distance for house construction by the present Ordinance Concerning Cliff (TYPE 5: Fig. 10(a), TYPE 6: Fig. 10(b), TYPE 7: Fig. 10(c)) with “45 deg. Line”. In Fig. 10(a), (b), (c), a lot of plots are distributed around 45 deg. Line. Based on the comparison between Fig. 9 and Fig. 10(a), (b), (c), the estimated accuracy of the slope failure range using the equations is improved by consideration of gradient of embankment slope 1:*s*.

However, a tendency to evaluate the slope failure range in “Safe Area” is strong comparatively with the present regulation of TYPE 5 by following equation (see Fig. 10(a)).

$$L=H+H\times s \qquad (3)$$

In addition, a tendency to evaluate the slope failure range in “Dangerous Area” is strong comparatively with the present regulation of TYPE 6 by following equation (see Fig. 10(b)).

$$L=H+0.5\times H\times s \qquad (4)$$

Moreover, in Fig. 10(c), the estimated slope failure range distributed in not only “Safe Area” but also “Dangerous Area” with the present regulation of TYPE 7 by following equation.

$$L=1.5\times H+0.5\times H\times s \qquad (5)$$

In Figs. 9 and 10(a), (b), (c), use of the present forbidden distance for construction of houses by Ordinance Concerning Cliff cannot estimate the slope failure range of a residential fill slope with sufficient accuracy.

Therefore, based on the findings acquired from the above-mentioned analyses, we proposed the new determination of the forbidden distance for house construction by Ordinance Concerning Cliff. Fig. 10(d) shows the estimated the failure range of the 510 artificial slopes were plotted with the new regulation of forbidden distance for house construction by following equation.

$$L=0.6\times H+0.9\times H\times s+0.91 \tag{6}$$

Where, equation (6) was constructed by not only the envelope spectrum of the estimated slope failure range of all 510 cases but also the minimum difference of the estimated range between parametric study and equation (6). Then, a residential fill slope with more than 3 m of the slope height H is interest for Equation (6) like the present forbidden distance for house construction by Ordinance Concerning Cliff (TYPE 1-7). The observed slope failure range of Asahidai Case (means maxium failure case) and Ryojo Case (means minimum failure case) in the 7 previously mentioned case histries were plotted with Fig. 10(d). In Fig. 10(d), 45 deg. Line has two kind of straight line, solid line is based on the actual failure range of the residential fill slope, and dashed line expresses the area of the extrapolation without the actual failure range of the residential fill slope. Note, applying the new proposed regulation in this study is not most suitable method for estimation of slope failure range. You should adopt the technique based on the concept of "Firstly Slip" and "Secondly Slip", if you already know the specifications of a residential fill slope of interest (for instance, characteristics of slope form, soil mechanics and so on).

CONCLUSIONS

In this study, we focused on the residential fill slopes failed in the past large-scale earthquake, and evaluated failure range of residential fill slopes, the 7 case histories. Based on the findings obtained by the 7 case histories, then, we carried out the parametric study with a lot of artificial slope models. Finally, we proposed new regulation of forbidden distance for house construction by Ordinance Concerning Cliff, based on the special issue of the present regulations.

1. Regardless of applicability criterion of the present regulation of forbidden distance for house construction, in all case histories of interest, the failure range of residential fill slopes reached the foundation of houses.
2. In predicting failure range of a residential fill slope during a future large-scale earthquake, we indicated the necessity of taking into consideration not only the effect of "Firstly Slip" but also the effect of "Secondly Slip".
3. The parameter to have a large influence on failure range of residential fill slope are slope height H and gradient $1{:}s$. Use of the present forbidden distance for construction of houses by Ordinance Concerning Cliff cannot estimate the slope failure range of a residential fill slope with sufficient accuracy.
4. The proposed new regulation of forbidden distance for house construction in this study has solved the special issue of the present regulation. Note, applying the new proposed regulation is not most suitable method for estimation of slope failure range. You should adopt the technique based on the concept of "Firstly Slip" and "Secondly Slip", if you already know the specifications of a residential fill slope of interest.

As a future study, we would like to improve the applicability of the proposal regulation of forbidden distance for house construction by increasing the number of case studies.

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