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TOPOGRAPHICAL EFFECTS ON WIND SPEED OVER VARIOUS TERRAINS: A CASE STUDY FOR KOREAN PENINSULA

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ABSTRACT

In this study, analysis of topography effects using two methods was undertaken and four case studies for Korean Peninsula are presented. The first method is using five different codes with ASCE 7-05, AS/NZS 1170.2:2002, EUROCODE 2004, AIJ 2004, KBC 2005, and the second is computational simulation. The present work investigates conditions to conjecture topographic factor effects using five different codes for undulating terrain in equally spaced eight wind directions. As a consequence of insufficient specifications from most wind codes, it is required to adopt parameter for upwind obstruction identified in ASCE 7-05 to other codes, which, in this paper, we called mixing parameter method (MPM). This work compares topographic factors between the original codes and using MPM in order to demonstrate the effects of undulating terrain, and also presented rationalized formula to comprehend the influential factors in each code. The resulting topographic factors are shown to be by the influence of different parameter in each code and slope of topography in the upwind direction. Computational fluid dynamics is applied to get topographical effects for comparison and to observe the altering flow of topographic factors along terrain. In addition, the results of topographic factors from codes are applied for 10 minutes average annual peak wind speed, recorded by Korea Meteorological Administration during 1971-2007. The aim of this application is to see the comparison wind speed for different ground feature condition, through conversion on identical ground feature, the flat ground.

KEYWORDS: TOPOGRAPHY EFFECTS, TOPOGRAPHIC FACTOR, WIND DIRECTIONS, CODES, COMPUTATIONAL SIMULATION, WIND SPEEDS

Introduction

The effects of topography on the wind flow near ground are immensely significant; however most wind codes only take into account the most critical situations of wind speed increase that occur near the crests of hills, ridges, escarpments, where the shape of ground feature is perfectly single hills, ridges, escarpments, excluding for case in undulating terrain.

The air flow over flat ground is already complex, thus changing the terrain to hills makes the air flow even more hard to understand. Topography or large vertical displacements of the ground surface can have significant effect on the wind speed profile. The wind flow in realistic environment is not merely over a single ground feature such hills, ridges, escarpment, but as well over undulating and mountainous terrain. It is important to understand that the flow over one hill will affect that around the next. The effects of undulating and mountainous terrain are almost similar to those of a very rough surface.

Ridges and escarpments are mainly two dimensional land feature, and hills are mainly three dimensional. Hills differ from ridges in that the wind can diverge over sides in addition to speeding up over crests. The speed-up effects of a hill are thus generally less than that those of a ridge of the identical slope. In general, wind increases its speed when it moves up the windward slope of a hill or a ridge. The maximum increase in wind speed is usually experienced at or near the crest.

Most codes read that the calculation of topographical effects is associated with ideal condition when the profile of ground feature is not undulating. This ideal condition is impracticable in actual environment where mostly features are undulating and mountainous terrain. Concerning these reasons, for instance in EUROCODE 2004 as specified in National Annex A.3, it reads that the orography factor (Co) accounts for the increase of mean wind speed over isolated hills and escarpments (not undulating and mountainous region). Both of KBC 2005 and AIJ 2004 do not specify regulations in relation to the presence of undulating or mountainous terrain. In KBC 2005 the topographic factors for the topography are defined simply by the inclination angles of the slope. AS/NZS 1170.2:2002 reads that the influence of any peak may be ignored, provided it is distant from the site of the structure by more than 10 times its elevation above sea level.

It seems that there exists no proper method. Furthermore, the differences in definition of the basic parameters for the wind codes generate significant difficulties for unifying five different wind codes. Owing to insufficient specifications from most wind codes, this study suggests an alternative due to the presence of undulating or mountainous terrain to investigate topographical effects. ASCE 7-05 explicitly specifies a regulation when terrain is undulating, particularly for upwind obstruction within 2 miles distance. This article identified in ASCE 7-05 was adopted to other codes, which, in this work it is called mixing parameter method (MPM).

Topography Effects Calculation Methodology

Most codes neglect the effects of topography when terrain is undulating, and simply assume that the shape of ground feature is perfectly single hills, ridges, and escarpments. Therefore, parameters and assumptions are established as a consequence of insufficient specification from codes itself and by reason of the inadequacy of information from case studies itself.

In this work, the methods used to analyze the topographical effects are by using five different codes and computational simulation. The topography in this case specify as two dimensional land features, namely ridges and escarpments. In order to predict topographic factors over various terrains, it is important to consider the effects of topography. The case studies were taken for four representative weather stations such as Busan, Chupungryeong, Ulleungdo and Jindo whose surround grounds are undulating. The survey was conducted using aerial images obtained from Google Earth©.

Most of codes are almost insensitive to the upwind obstruction which refers to section 6.5.7 of ASCE 7-05. Hence, upwind obstruction parameter identified in ASCE 7-05, was adopted to other codes, which, it is called mixing parameter method (MPM). Figure 1 below shows the illustration of upwind obstruction adopted from ASCE 7-05, which should be within 2 miles distance. Topographic factors are calculated using codes with MPM and the original codes.

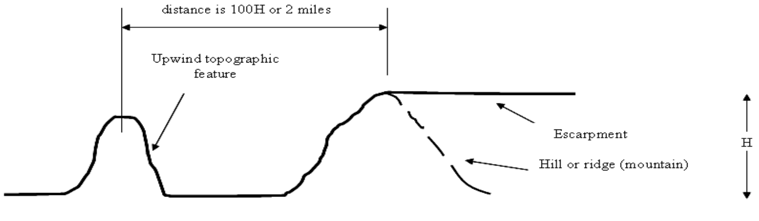

Figure 1: Illustration of upwind obstruction (adopted from ASCE 7-05)

The analysis is focused here mainly on two-dimensional ground feature. Figure 2 below shows illustration of specifications on 2-D ridges, escarpments and local topographic zone, where, x is the horizontal distance of structure from the crest, upwind or downwind; ϕ is upwind slope; Lu is horizontal distance upwind to half height below crest. In this work, to assess the effect of topography, an assumption was taken for H, which the height of hills, ridges, escarpments, in which H is regarded as the difference between the height of highest ground and the height of the lowest ground. Z is vertical distance of structure above local ground, assumed to 10 m. Location of structures (site) is essential to be considered. ASCE 7-05 specifies that wind speed-up effects shall apply if the site is on the upper half of a hill, ridge or near the crest of an escarpment. AS/NZS 1170.2:2002 and KBC 2005 read that the site should be within the local topographic zone as shown in table 1.

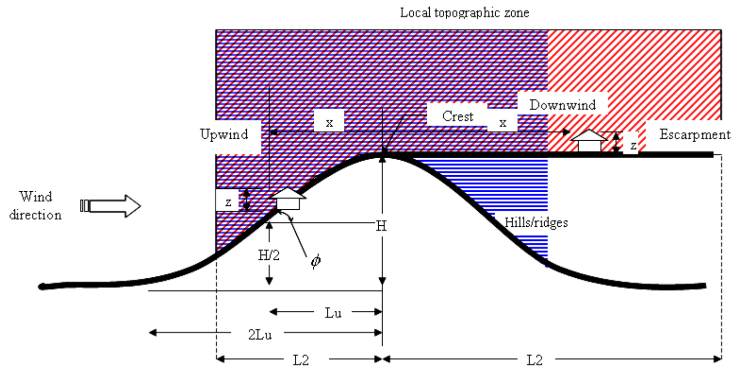

Figure 2 Illustration of 2-D ridges and escarpments local topographic zone

Table 1 Boundaries reflecting the wind speed-up factor for topography (local topographic zone)

Topographic categories	Boundary reflecting wind speed-up factor	Scope of applications			
		Windward		Leeward	
		AS/NZS 1170.2:2002	KBC 2005	AS/NZS 1170.2:2002	KBC 2005
Hills/ridges	Vertical length (above ground surface)→ L1	The greater of 0.36Lu or 4H	The greater of Lu and 1.7H	The greater of 0.36Lu or 4H	The greater of Lu and 1.7H
	Horizontal length (above crest)→ L2	to be taken as 4L1	The greater of 1.5Lu and 2.5H	to be taken as 4L1	The greater of 1.5Lu and 2.5H
Escarpments	Vertical length (above ground surface)→ L1	The greater of 0.36Lu or 4H	The greater of Lu and 1.7H	The greater of 0.36Lu or 4H	The greater of Lu and 1.7H
	Horizontal length (above crest)→ L2	to be taken as 4L1	The greater of 1.5Lu and 2.5H	to be taken as 10L1	The greater of 3Lu and 5H

Table 2 below shows the topographic factors formula for each code to calculate topographic factors. Other codes have specific formula to calculate topographic factors while KBC 2005 does not specified and it simply depending on inclination angle (ϕ) which refers to table 0305.6.5(1) of KBC 2005.

Table 2 Topographic Factor Formula for Codes

ASCE 7-05	AS/NZS 1170.2:2002	EUROCODE 2004	AIJ 2004	KBC 2005
Kzt = $(1+K1K2K3)^2$ K1 = H/Lh K2 = x/Lh K3 = z/Lh → $\sqrt{Kzt}$	• For H/(2Lu)<0.05, Mh= 1.0 • For 0.05 ≤ H/(2Lu) < 0.45 and within the local topographic zone for H/(2Lu)>0.45 $Mh = 1 + \left(\frac{H}{(3.5(z+L1))}\right)\left(1-\frac{\lvert x \rvert}{L2}\right)$ • For H/(2Lu) > 0.45, within the separation zone $Mh = 1 + 0.71\left(1-\frac{\lvert x \rvert}{L2}\right)$ • For the case where x and z are zero, the value of Mh is give in table of AS/NZS 1170.2:2002.	• Co = 1, for ϕ< 0,05 • Co = 1+ 2 .s. ϕ , for 0,05<ϕ<0.3 • Co = 1+ 0,6 .s , for ϕ> 0,3	$E_g = (C_1 - 1)\left\{C_2(\frac{Z}{Hs} - C_3) + 1\right\}\exp\left\{-C_2(\frac{Z}{Hs} - C_3)\right\} + 1 \geq 1$ If E_g less than 1, then E_g shall be taken as 1	Kzt is depending on inclination angle (ϕ). There is no specific calculation and wind speed-up factors for topography (Kzt) are defined in suitable table of KBC 2005.

Results and Discussion

Geophysical Features of Case Studies

In this study, upwind slope less than 0.3 is referred as shallow, while it exceeding 0.3 as steep. Table 3 below shows the slopes for all case studies which are mostly shallow, except for Busan station in west wind direction and Jindo station in East and SE wind direction.

Table 3 Upwind slope and slope for case studies

Wind directions	BUSAN		CHUPUNGRYEONG		ULLEUNGDO		JINDO	
	Upwind slope (ϕ)	Slope (θ)	Upwind slope (ϕ)	Slope (θ)	Upwind slope (ϕ)	Slope (θ)	Upwind slope (ϕ)	Slope (θ)
N	0.14	7.97°	0.14	7.79°	0.2	11.31°	0.18	10.2 °
S	0.1	5.71°	0.16	9.09°	0.15	8.53°	0.18	10.2°
E	0.055	3.14°	0.1	5.71°	0.21	1.86°	0.33	18.26°
W	0.41	22.29°	0.18	10.2°	0.15	8.5°	0.21	11.86°
NE	0.11	6.27°	0.18	10.2°	0.12	6.84°	0.14	7.97°
SW	0.25	4.04°	0.3	16.7°	0.13	7.4°	0.29	16.17°
NW	0.28	5.64°	0.25	14.04°	0.17	9.64°	0.14	7.97°
SE	0.22	12.4°	0.1	5.71°	0.14	7.97°	0.38	20.81°

All case studies can be classified into three categories. In the figures below, the triangle marks are indicated the location of the structure is located. As shown in Figure 3, the first category is defined as the location in the middle of the upwind obstruction domain, where the structure is lower than the highest ground and higher than the lowest ground. This category is divided into two, depending on whether the nearest ground feature is a ridge, represented by case in Busan NE-SW or an escarpment, represented by case in Ulleungdo N-S.

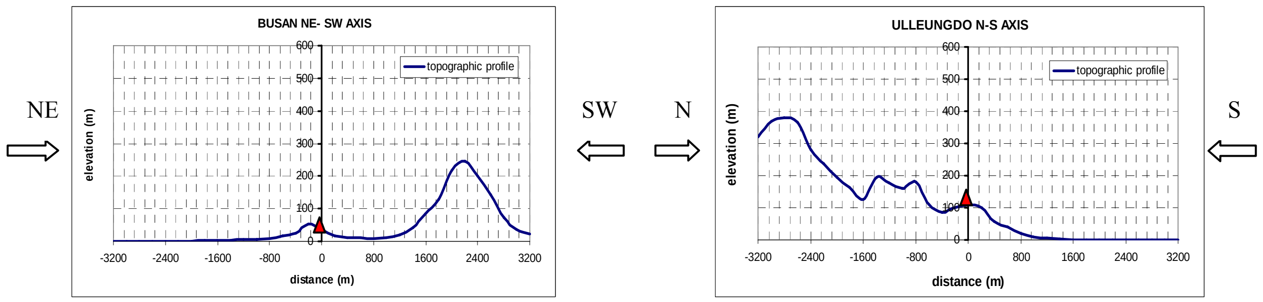

Fig. 3 First category of geophysical features

As shown in Figure 4, second category is defined as the location in the middle of the upwind obstruction domain, where the structure is lower than the both of ground side. This category is also divided into two, depending on whether the nearest ground feature is a ridge, represented by case in Busan NW-SE or the nearest ground feature is a flat ground, represented by case in Chupungryeong E-W.

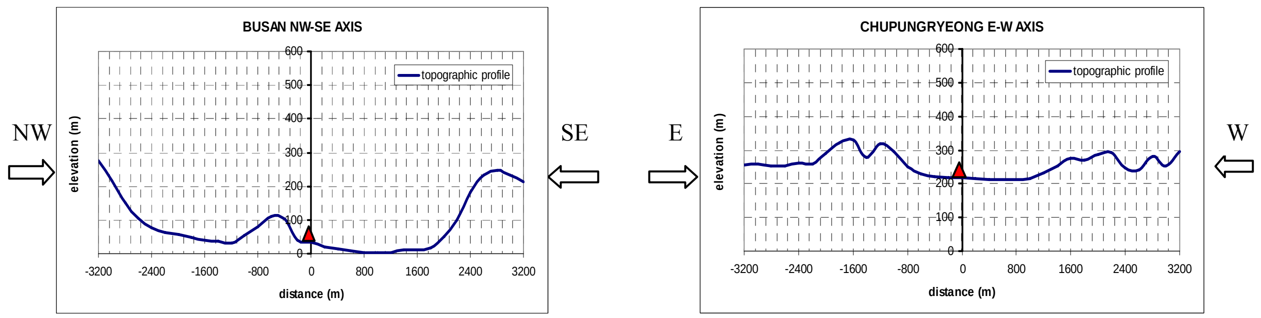

Fig. 4 Second category of geophysical features

As shown in Figure 5, third category is defined as the location in the middle of the upwind obstruction domain, where the structure is higher than the both of ground side. This category is represented by case in Ulleungdo NE-SW where the structure is near the crest of a ridge, and on the top of ridge represented by case in Jindo E-W.

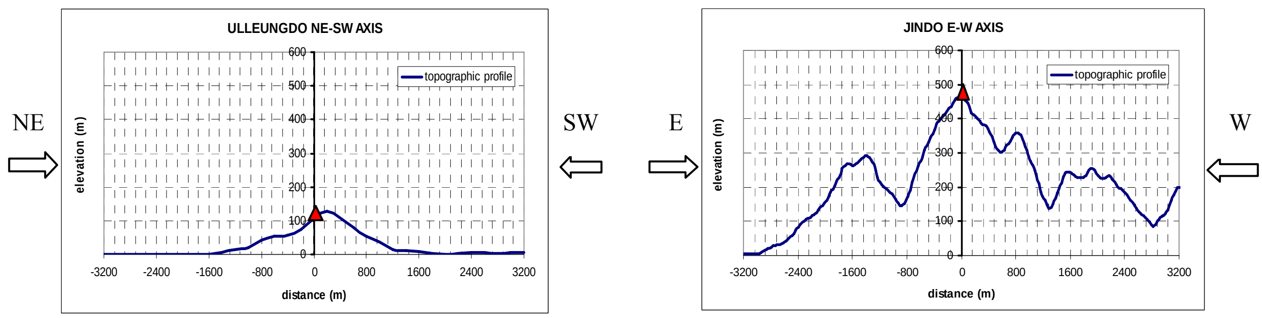

Fig. 5 Third category of geophysical features

Topographic Factors Using Codes

Table 4 shows the comparison of topographic factors between the original codes and using MPM. Note that topographic factors using MPM in ASCE 7-05 are identical to those using the original, since it meets all the requirements condition. In AIJ 2004, the topographic factors are mostly 1.00, because AIJ 2004 reads that topography effect in the slope less than 7.5^{o} can be neglected. In case study of Chupungryeong station for all wind directions, the structures is on the flat ground in the valley, where the structure is lower than both of ground side; hence topographic factors are 1.00 for all codes. From these tables, it is also found that topographic factors using the original codes tend most likely to be greater than those using MPM.

Big discrepancy between values using MPM and the original has found in KBC 2005 for case in Busan-north wind direction. The topographic factor using the original is 1.21, while using MPM gives of 1.00. Differences relatively large are caused by consideration upwind obstruction within 2 miles distance from the location of the structure. In this case, when topographic factor is calculated using MPM, this condition considers the upwind obstruction and the highest ground is taken as a reference based on the direction the wind. According to the KBC 2005 regulations, the wind speed-up effects shall apply if the structure is within the local topographic zone near the top. But for this site with the wind from the north, topographic factor shall be taken as 1.00 because the structure is reach out of local topographic zone. Based on analysis using KBC 2005, it is identified that the upwind slope for Busan-north wind direction is 0.1, so the topographic factor is 1.21. Compared to ASCE 7-05, topographic factor in KBC 2005 has identical result when it calculated by using MPM.

For case in Busan-NE, topographical factors from ASCE 7-05 and KBC 2005 shows relatively large difference. In ASCE 7-05, topographic factor is influenced by hill shape factor, distance of structure factor, and height of building factor; but KBC specifies only hill shape factor to consider topographic factor. Associated with these differences, it will be highlighted in rationalized formula in the next section. In case of Jindo, the location of structures is at the crest of ridge. Theoretically, the value of topographic factor is maximum if the structure located at the crest of the ridge. The topographic factors using MPM and the original codes are identical, due to the location of all structures. Compare to other codes, ASCE 7-05 has the biggest value of topographic factors for all wind directions.

Table 4 Comparison of topographic factors between the original codes and using MPM

Wind directions	ASCE 7-05		AS/NZS 1170.2:2002		EUROCODE 2004		AIJ 2004		KBC 2005	
	Original Codes	Using MPM	Original Codes	Using MPM	Original Codes	Using MPM	Original Codes	Using MPM	Original Codes	Using MPM
BUSAN										
N	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.00	1.21	1.00
NE	1.08	1.08	1.04	1.04	1.09	1.09	1.00	1.00	1.21	1.21
CHUPUNGRYEONG										
S	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
W	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ULLEUNGDO										
N	1.00	1.00	1.13	1.00	1.19	1.00	1.19	1.00	1.18	1.00
SW	1.24	1.24	1.14	1.14	1.16	1.16	1.00	1.00	1.26	1.26
JINDO										
N	1.51	1.51	1.30	1.30	1.25	1.25	1.30	1.30	1.36	1.36
E	1.72	1.72	1.54	1.54	1.42	1.42	1.30	1.30	1.61	1.61

Rationalized Formula for Codes

In order to identify the influential factors in each code, this study presented rationalized formula of the codes by using ASCE 7-05 as criterion. Topographic factor for most codes is influenced by hill shape factor, distance of structure factor, and height of building factor; but in KBC specifies only hill shape factor to consider topographic factor. Table 5 is rationalized form of codes for selected representative case.

Table 5 Rationalized formula for codes

ULLEUNGDO-EAST					
Codes	K1 (hill shape factor)	K2 (distance of structure factor)	K3 (height of building factor)	Topographic factors	Note
ASCE 7-05	0.36	0.88	0.54	1.17	$Kzt = (1 + K1K2K3)^2 \rightarrow \sqrt{Kzt}$ $K1 = \frac{H}{Lu}$ $K2 = \frac{x}{Lu}$ $K3 = \frac{z}{Lu}$
AS/NZS 1170.2:2002	0.33	0.65	0.94	1.20	$Mh = 1 + K1K2K3$ $K1 = \frac{H}{1.26Lu}$ $K2 = 1 - \frac{x}{1.44Lu}$ $K3 = \frac{1}{1 + \frac{z}{0.36Lu}}$
EUROCODE 2004	2 x 0.21	0.45		1.19	$Co = 1 + 2K1(K2, K3)$ $(K2, K3) = s =$ orographic location factor, determined from figure A2, A3 in Eurocode 2004 $K1 = \phi = \frac{H}{A} = \frac{H}{2Lu}$
KBC 2005	0.21	-	-	1.18	$K1 = \phi = \frac{H}{2Lu}$. Kzt is depending on ϕ, the value of Kzt determined from the table for Kzt in KBC 2005.

Comparisons between Codes and Computational Simulation

Table 6 below has shown the comparison results between codes and computational simulation for selected wind directions. Compare to the results from computations, it is found that some of topographic factor by codes are under estimated or over estimated. For case in Busan-NE wind direction, it is found in KBC 2005 that there is a difference of 18.6%. In case of Ulleungdo-NE wind direction, it is found in KBC 2005 that there is a difference of 8.62 %. It is identified that the ground feature for Ulleungdo-NE wind direction is perfectly single ridge. Other than AIJ 2004 topographic factor value is 1.00, since the slope is less than 7.5º. Moreover, for case in Ulleungdo-SE wind direction, it is found in KBC 2005 there is relatively large difference of 28.43 % compare to computations. The topographic factors for Chupungryeong have a good agreement between codes and computations. In case of Jindo-east, AIJ 2004 shows relatively large difference about 27.77 % compare to computations.

Table 6 Comparison between topographic factors between codes and computational for cases studies

Wind directions	ASCE 7-05	AS/NZS 1170.2:2002	EUROCODE 2004	AIJ 2004	KBC 2005	Computational
BUSAN						
NE	1.08	1.04	1.09	1.00	1.21	1.02
SW	1.00	1.00	1.00	1.00	1.00	1.00
CHUPUNGRYEONG						
Wind directions	ASCE 7-05	AS/NZS 1170.2:2002	EUROCODE 2004	AIJ 2004	KBC 2005	Computational
SE	1.00	1.00	1.00	1.00	1.00	1.00
ULLEUNGDO						
Wind directions	ASCE 7-05	AS/NZS 1170.2:2002	EUROCODE 2004	AIJ 2004	KBC 2005	Computational
NE	1.24	1.14	1.12	1.00	1.26	1.16
SE	1.29	1.14	1.14	1.07	1.31	1.02
JINDO						
Wind directions	ASCE 7-05	AS/NZS 1170.2:2002	EUROCODE 2004	AIJ 2004	KBC 2005	Computational
E	1.72	1.54	1.42	1.30	1.61	1.80
NW	1.41	1.24	1.20	1.37	1.31	1.51

Figures 6, 7 and 8 below have shown figures of topographic profile with topographic factors from computational results for case of Busan-NE, Ulleungdo-NE, and Jindo-NW. In these figures, we can observe the altering flow of topographic factors along terrain, which has identical pattern with terrain feature. When analysis of topographic effect using the codes was undertaken, it is simply based on the slope itself, and then single value is acquired. Consequently, we cannot observe the altering flow of topographic factors along terrain.

(a)

(b)

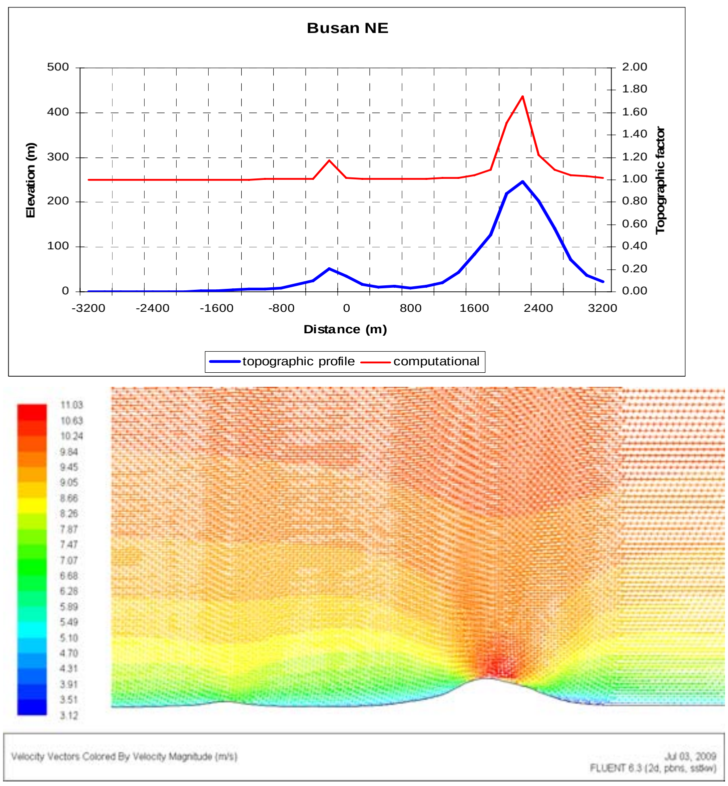

Fig. 6 Case in Busan-NE wind direction, (a) Topographic factors from computational result, (b) Velocity vectors

(a)

(b)

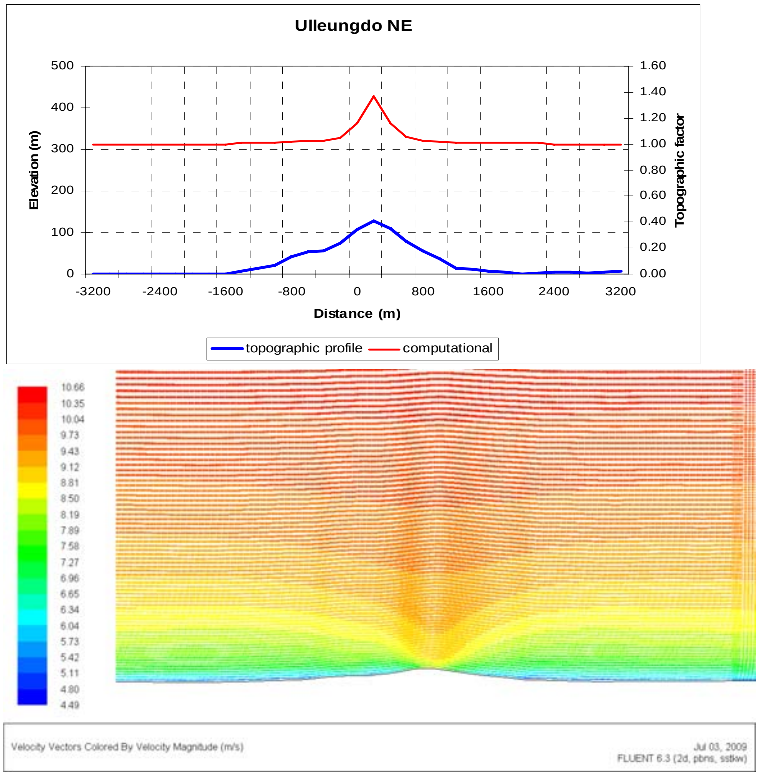

Fig. 7 Case in Ulleungdo-NE wind direction, (a) Topographic factors from computational result, (b) Velocity vectors

(a)

(b)

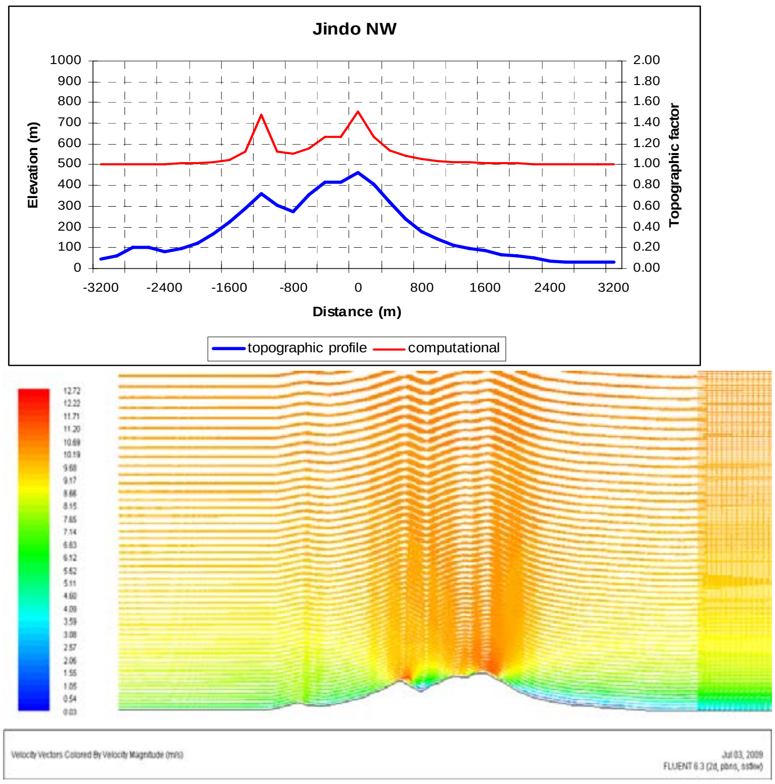

Fig. 8 Case in Jindo-NW wind direction, (a) Topographic factors from computational result, (b) Velocity vectors

Application to Annual Peak Wind Speed Estimation

Using the results, 10 minutes average annual peak wind speeds measured at the corresponding sites are modified to get homogeneous wind in open terrain. It can be seen in Figure 9 as representative case, the comparison of annual peak wind speed the original and using MPM for case in Ulleungdo-north wind direction, shows that the conversed wind speed has strong and weak effects to the codes when it is compared the wind speeds between actual measurements and the original codes. The strongest effect is found for ASCE 7-05. Weak effects are found in EUROCODE 2004, AIJ 2004, and KBC 2005. While the results of wind speed conversion between actual measurements and using MPM are identical.

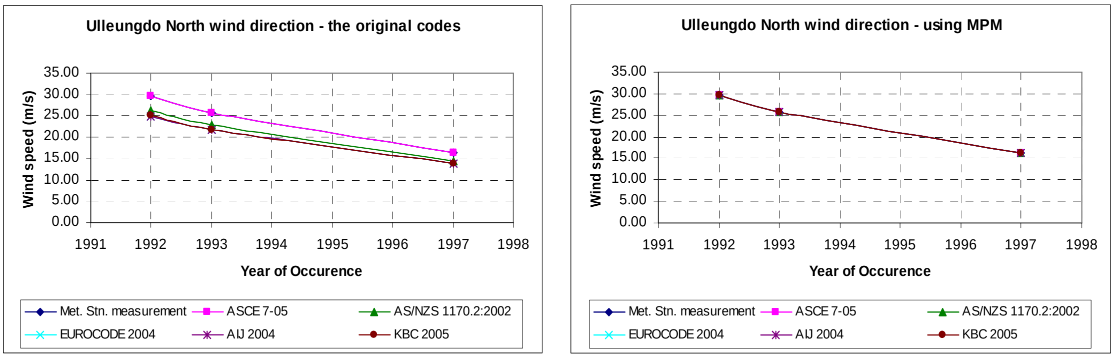

Fig. 9 Comparison of conversion annual peak wind speed between the original codes and using MPM for case in Ulleungdo-north wind direction

Conclusions

In this study, the main concern is associated with topographical effects. The presence of hills, ridges and escarpments can have significant number of effects in different scales of topographic factor. Hills differ from ridges in that the wind can diverge over sides in addition to speeding up over crests. The degree of topographic effects for hill is thus generally less than that for a ridge of the identical slope.

The investigation of topographical effects is using two methods. First is using five different codes both of the original and using MPM for four sites in Korean Peninsula. The second method is computational simulation for 2-D terrain. Calculation of topographical factors using the original codes is simply considers the ground feature where the structure is located, without consideration of the other vicinity topographic feature. In realistic environment, it seems that codes are impracticable. The presence of other shape of topography will affect topographic factor.

In the considered geophysical features of case studies it is found that types of slope for all case studies are mostly shallow. For shallow topography, no separation of flow occurs. The topographic factor is shown different results by the influence of different parameter in each code and slope of topography in direction wind is blowing. In the comparison of topographic factors, it is found that topographic factor value using the original codes are tended most likely to be greater than that using MPM. The rationalized formula among the codes also has been highlighted to comprehend why the results of topographic factor in each code are different when the wind comes from the identical direction. Hence, it is found that topographic factors are influenced by hill shape factor, distance of structure factor, and height of building factor.

The present work as well investigates application to conversed annual peak wind speed with 10 minutes average annual peak wind speed, which is recorded by Korea

Meteorological Administration during the period of 1971-2007 for all case studies. The conversed wind speed has strong and weak effects to the codes when compare the wind speeds between actual measurements and the original codes. The conversed wind speed using MPM is mostly agreed well with the actual measurements.

In this study, it is found that codes underestimates topographical effects when terrain is undulating, therefore it requires to investigate more for the terrain of undulating and mountainous. In spite of complexity involved in evaluating the topographical effects for undulating and mountainous terrain, there is an obvious necessity for an international harmonization of calculating methods for the topographical effects, particularly when terrain is undulating.

Acknowledgment

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