WIND PROPERTIES FOR DESIGN OF HIGHWAY BRIDGES

by

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ABSTRACT

In wind resistant design of highway bridges, it is necessary to clarify characteristics of strong wind. The Wind Resistant Design Manual for Highway Bridges [1] provides design wind speed and turbulence properties for plane-like terrains, but the effects of local topography were not included. In this paper, described are the effects of valleys on wind properties. Wind tunnel studies for real valley models and simplified valley models are described first. Then CFD is applied to wind properties in the simplified valley models.

KEYWORDS: wind properties, topographic effects, valley, Computational Fluid Dynamics

1. INTRODUCTION

In wind resistant design of highway bridges, it is necessary to clarify characteristics of strong wind, such as basic wind speed and turbulence intensity. In Japan, these characteristics can be decided according to "the Wind Resistant Design Manual for Highway Bridges"[1] (hereinafter referred as to 'the Manual') as follows.

1) Category of surface roughness
Wind properties were modeled fundamentally according to Davenport [2][3], namely, lower mean wind speed but higher turbulence in rough terrian and low altitude, and higher mean wind speed but lower turbulence in smooth terrian and high altitude. The terrians are classified into four, namely rough sea (Terrain Ⅰ), open farmland(Terrain Ⅱ), suburbs(Terrain Ⅲ) and city centers(Terrain Ⅳ).

2) Basic wind speed U10
The basic wind speed U10 is defined as the mean wind speed over open farmland(Terrain Ⅱ)at an elevation of 10m, averaged over a period of 10minutes. Using the meteorological data at weather stations in Japan, extreme wind speeds were estimated. The probability that the annual maximum mean wind speed exceeds the basic wind speed is 40% in a 50-year period. The basic wind speeds were classified into 4 categories, namely 35m/s, 40m/s, 45m/s and 50m/s. It is shown in Fig.1.

3) The design wind speed Ud
The design wind speed for dynamic design can be obtained from the following formula.
Ud=U10*E1
where, E1: correction factor for altitude and terrains
The model of design wind speed profiles are shown in Fig.2.

4) Turbulence properties
Typical values for turbulence properties such as turbulence intensities and power spectal density functions are provided in the Manual. Turbulence intensity Iu is shown in Fig.3.

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The geographical features of Japan are steep and complicated because of many high mountains and valleys, and sometimes affect characteristics of strong wind. It is difficult to predict the characteristics of strong wind at complicated topographic conditions. Several studies were conducted for simple and typical topographic conditions, such as terraces, independent peaks, ridges, valleys and so on. For example, it was found that wind speed increases considerably, when wind direction is along an open valley [4]. The details of this channelling effect, however, are not so clear.

The local topographic effects on strong wind are not considered in 'the Manual'. When a bridge is conducted at a complicated topographic site, some correction will be required for design wind properties. The most accurate way of investigating local wind properties is field survey at the site, but it would take much cost and time. Another way is to conduct wind tunnel test using topographical models. The CFD (Computational Fluid Dynamics), which has been developed remarkably, will be one of the possible prediction methods in near future.

In this paper, described are wind tunnel studies on the topographic effects. Models of the real valley and the simplified valley were used. Furthermore, CFD technique was applied to the simplified model.

2. WIND TUNNEL STUDY FOR THE REAL VALLEY MODELS. [5]

The valley was facing the Sea of Japan and its depth was about 70 meters (Fig.4). The traffic accident occurred on the bridge across the valley because of the strong wind [6]. The wind-rose shows that wind along the valley is distinguished, and wind from sea is stronger than wind from land (Fig.5).

2.1 Experimental Conditions

2 models (photo 1,2) were used. Their scale ratios were 1/600 and 1/1,500. Wider area was modeled in case of scale ratio 1/1,500 (Fig. 6). The test was conducted in the Gottingen type wind tunnel (cross-section is 2.5m×4m) of the Public Works Research Institute. The profile of approaching flow is shown in Fig.7. Wind speed and turbulence intensity were measured in the sections A,B and C (Fig.4).

2.2 Characteristics of the Strong Wind in the Valley

The measured wind speed was divided by the wind speed of the approaching flow at the same altitude as the measuring point, and the ratios are shown in Fig8.

The approaching flow is increased at the section B, where cross sectional area becomes smallest, and decreased at the section C (Fig.8 (a)-(c)). In the cross section of the valley, wind speed ratio becomes maximum near the slope of the valley (Fig.8(b),(d)), not in the center of cross section.

2.3 Influence of the Model Scale and Range

Although details of topographic features were reproduced in case of the 1/600 model, the modeled range was narrower than 1/1,500 model. For example, the mountain whose altitude was about 300m and the cape around the valley were not included in 1/600 model. The wind speed ratio distribution of the two models are, however, almost similar (Fig.8 (b),(d)). It seems that wind properties are strongly influenced by local geographical condition rather than surrounding geographical condition in case of valleys like this.

2.4 Influence of the Model Roughness

Sponge-like resin was stuck on the surface of the 1/600 model, and influence of surface roughness was investigated. In the case of rough surface model, the turbulence intensity is stronger and the wind speed ratio is smaller than the smooth-surface model near the slope (Fig.8(b),(e),(f),(g)). It seems that the surface condition should be simulated properly to represent wind properties near the slope of valleys.

3. WIND TUNNEL STUDY FOR SIMPLIFIED VALLEY MODELS [5]

3.1 Experimental Conditions

Simplified valley models were used to investigate parametrically the effects of width and slope of the valley. The models and experimental conditions are shown in Fig.9 and Table 2, respectively. Two types of approaching flow were used, and their vertical profiles are shown in Fig.10. Mean wind speed and turbulence intensity were measured at the section I and II as are shown in Fig.9, and the wind speed ratios were calculated.

3.2 Wind Speed Distribution

In the Section I along wind direction, the wind speed ratio becomes maximum around the entrance of the valley, and it gradually decreases along the valley (Fig.11). Turbulence intensity shows reverse tendency (Fig.12). In the cross section II the wind speed becomes maximum near the slope of the valley, but not at center of the valley (Fig.13). This tendency is similar to the result of the real valley model.

3.3 Influence of Valley Width

The maximum value of the wind speed ratio increases, as the valley width becomes narrower as is shown in cases 2 to 5 in Table 2.

3.4 Influence of Valley Slope

Among three slope angles, 45deg, 60deg and 90deg, the wind speed ratio became maximum at the slope of 60deg (Cases 1 to 3 and 6 to 8 in Table 2). It seems that slope angle affected both cross section area of the valley and separation of the flow, and that these effects resulted in the maximum wind speed ratio at the 60deg slope.

3.5 Influence of Vertical Profile of Approaching Flow

Between the two kinds of approaching flow, vertical profiles of mean wind speed were almost same, but vertical profiles of turbulence intensity were not. Turbulence intensity at the height of the valley (H=100mm) of approaching flow 1 was about 3%, and that of approaching flow 2 was about 8%. The maximum value of the wind speed ratio for approaching flow 1 was around 1.2. The maximum value was increased in case of approaching flow 2, which was more turbulent (Cases 1 to 3 and 6 to 8 in Table2).

4 APPLICATION OF COMPUTATIONAL FLUID DYNAMICS TO THE SIMPLIFIED VALLEY MODELS [7]

CFD technique was applied to the Cases 1 to 3 of the simplified valley models. The analysis area is shown in Fig.14. The number of meshes was $60 \times 40 \times 50$, and the interval of mesh was narrower around the entrance of the valley than the other area. As for the turbulence model, standard K-ε model was used. The wind speed profile near the ground was assumed to accord with power law (n=1/6), whose power was the same as the approaching flow 1

The maximum value of the wind speed ratio was a little larger than the result of the wind tunnel test (Table 2 and Table 3). The difference becomes large near the ground (Fig.11 and Fig.15). It seems that the boundary conditions near the ground should be improved for this calculation. In qualitative point of view, however, CFD results agreed fairly well with the experimental results, namely wind speed increased near the entrance of the valley, and decreased along the valley. These result suggests that CFD would be applicable to the prediction of wind properties in near future.

5. CONCLUDING REMARKS

The effects of valleys on wind properties were studied by wind tunnel tests and CFD. The major findings are as follows.

Wind tunnel study for real valley models:
1) The approaching flow was increased at the smallest section, and decreased along the valley.
2) In the cross section of the valley, wind speed ratio became maximum near the slope of the valley, not in the center of cross section.
3) Wind properties were strongly influenced by local topographical condition rather than surrounding geographical condition in the valleys.
4) Surface condition should be simulated properly to represent wind properties near the slope of valleys.

Wind tunnel study for simplified valley models:
5) The maximum value of the wind speed ratio increased as the valley width becomes narrower.
6) Among three slope angles, 45deg, 60deg and 90deg, the wind speed ratio became maximum at the slope of 60deg.
7) Vertical profiles of turbulence intensity of approaching flow affected the maximum value of the wind speed ratio.

CFD study for simplified valley models:
8) CFD results agreed qualitatively well with the experimental results. In the future CFD would be applicable to the prediction of wind properties.

6. REFERENCES

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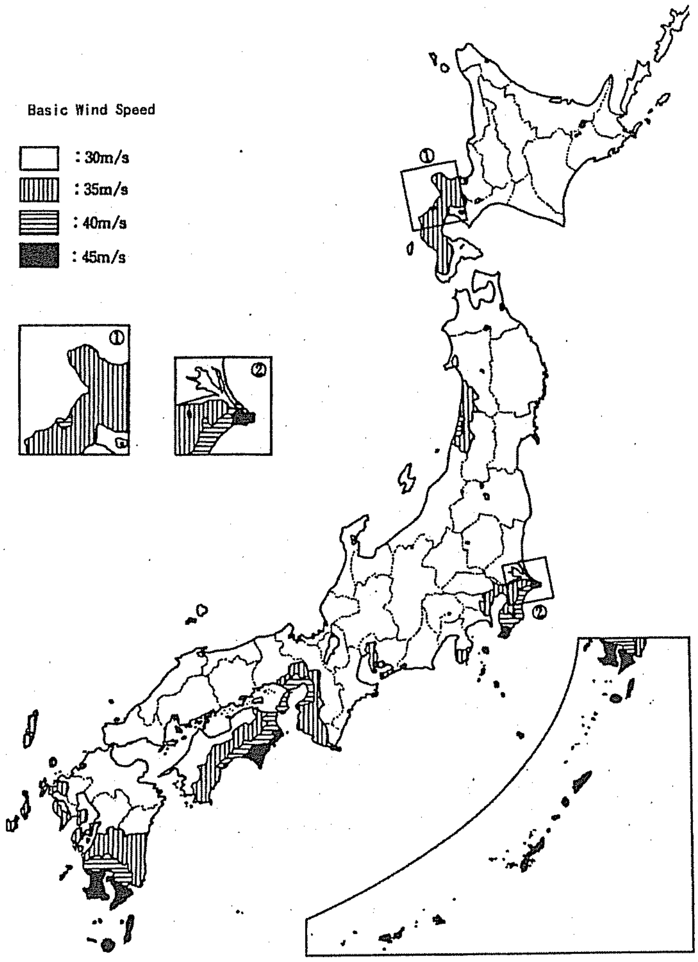


Fig.1　Basic Wind Speed

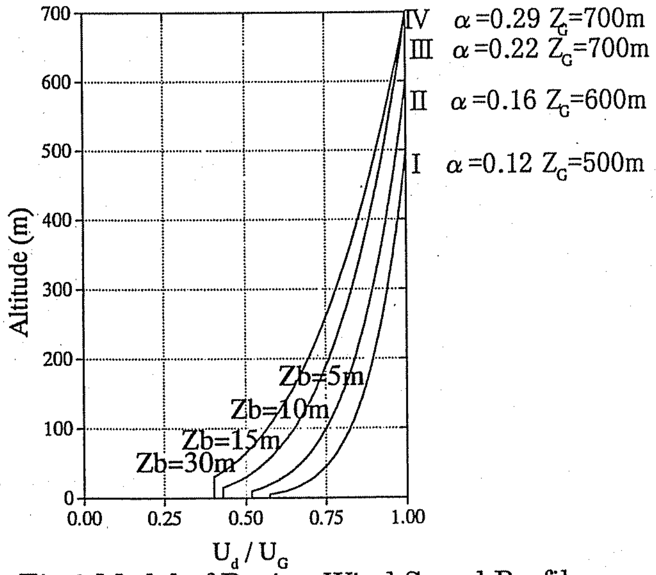


Fig.2 Model of Design Wind Speed Profiles

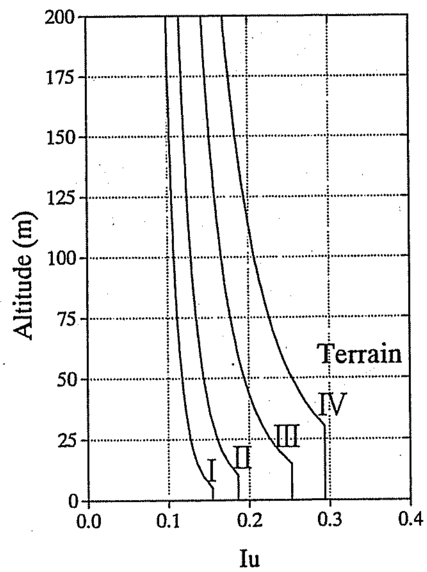


Fig.3 Turbulence Intensity

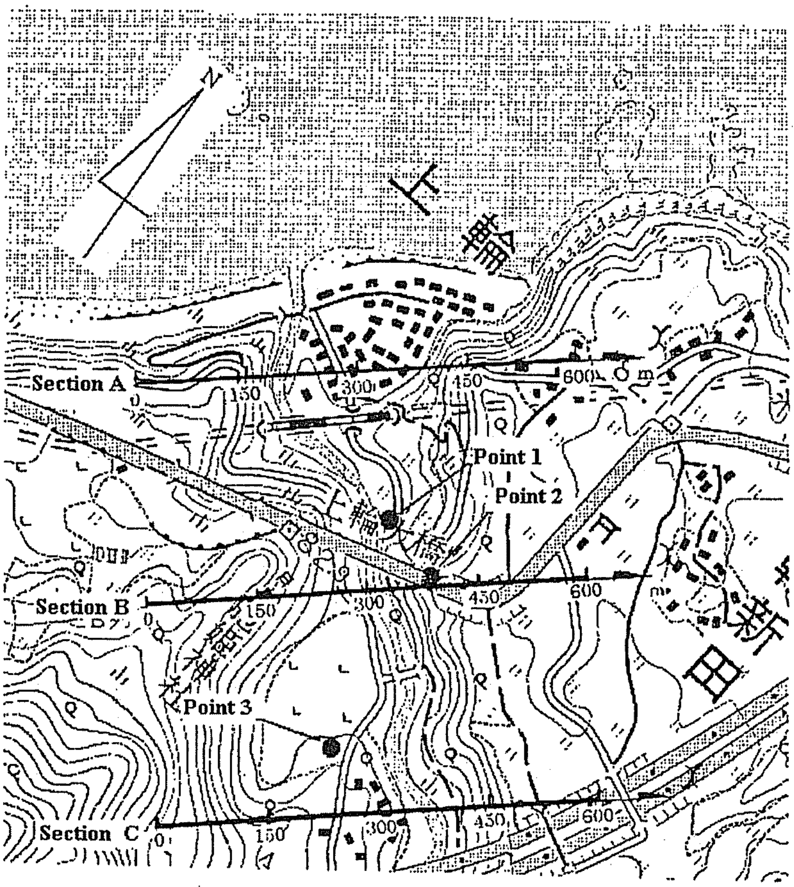
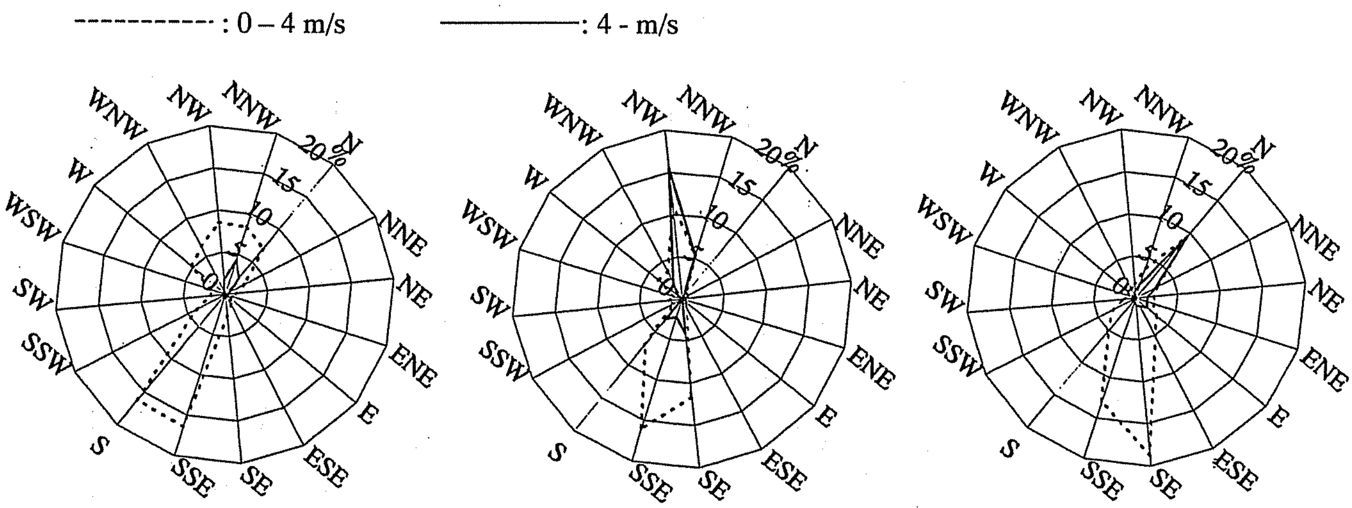


Fig.4 Measurement Sections and Observation Points



(a) Point 1 (b) Point 2 (c) Point 3

Fig.5 Wind Rose

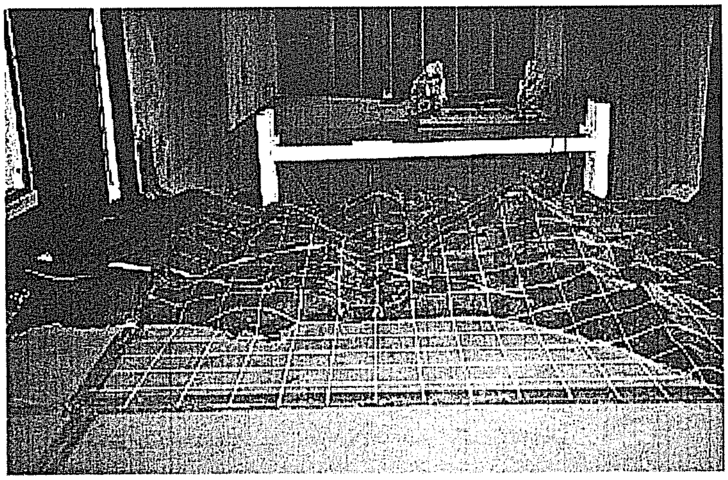


Photo 1　1/1,500 Model

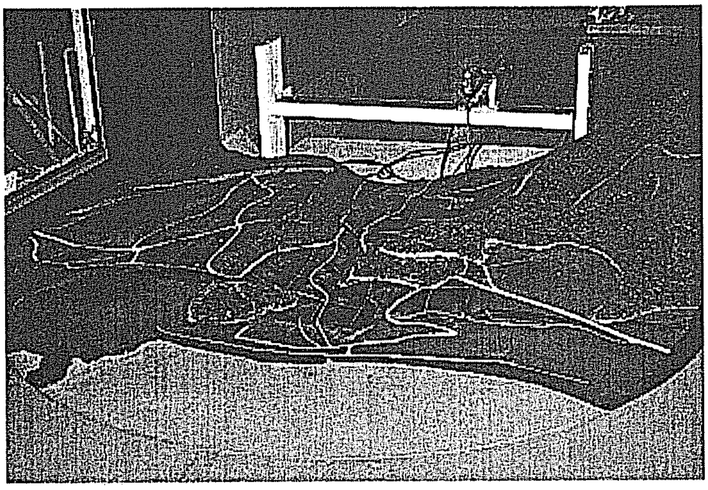


Photo 2　1/600 Model

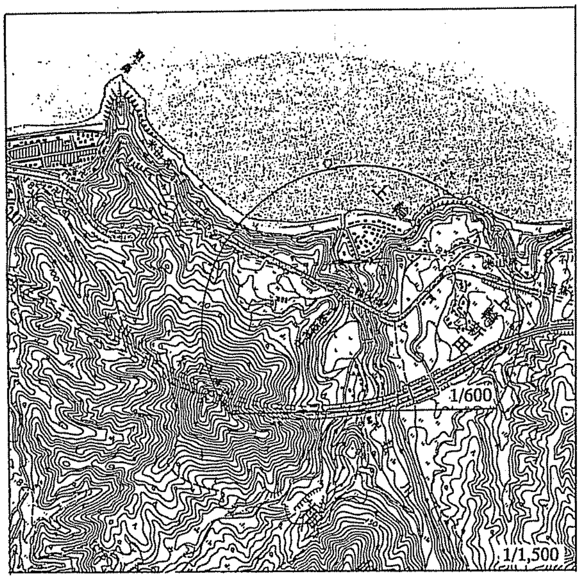


Fig.6　Range of Models

Table 1 Conditions of Wind Tunnel Study for Real Valley

	scale	wind direction	surface roughness	approaching flow
CASE1	1/600	NW	ignored	flow 1
CASE2	1/1,500	NW	ignored	flow 2
CASE3	1/600	NW	considered	flow 1

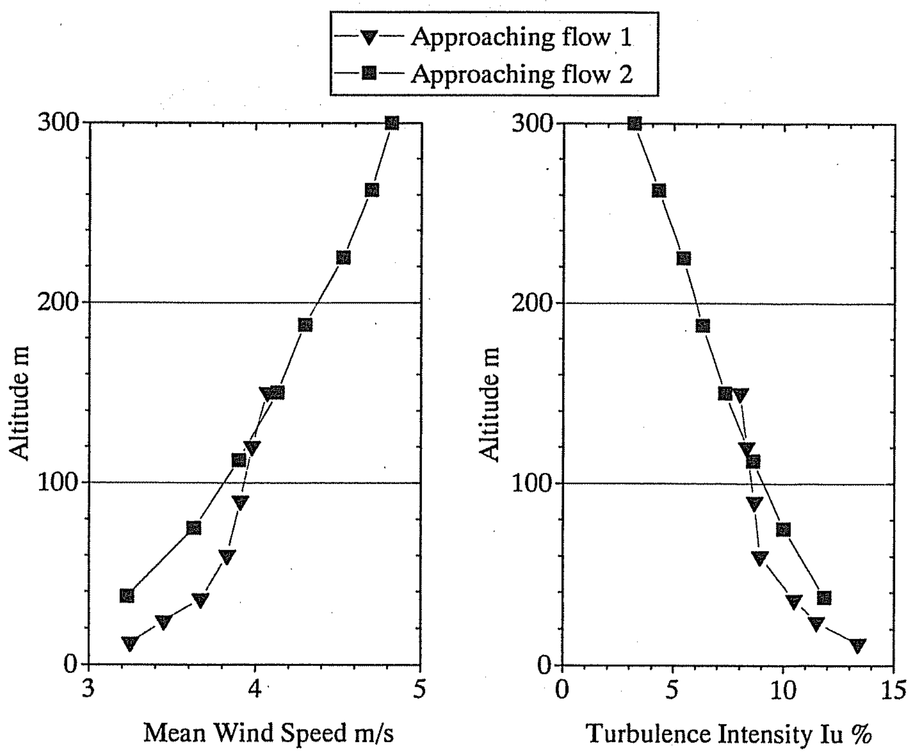
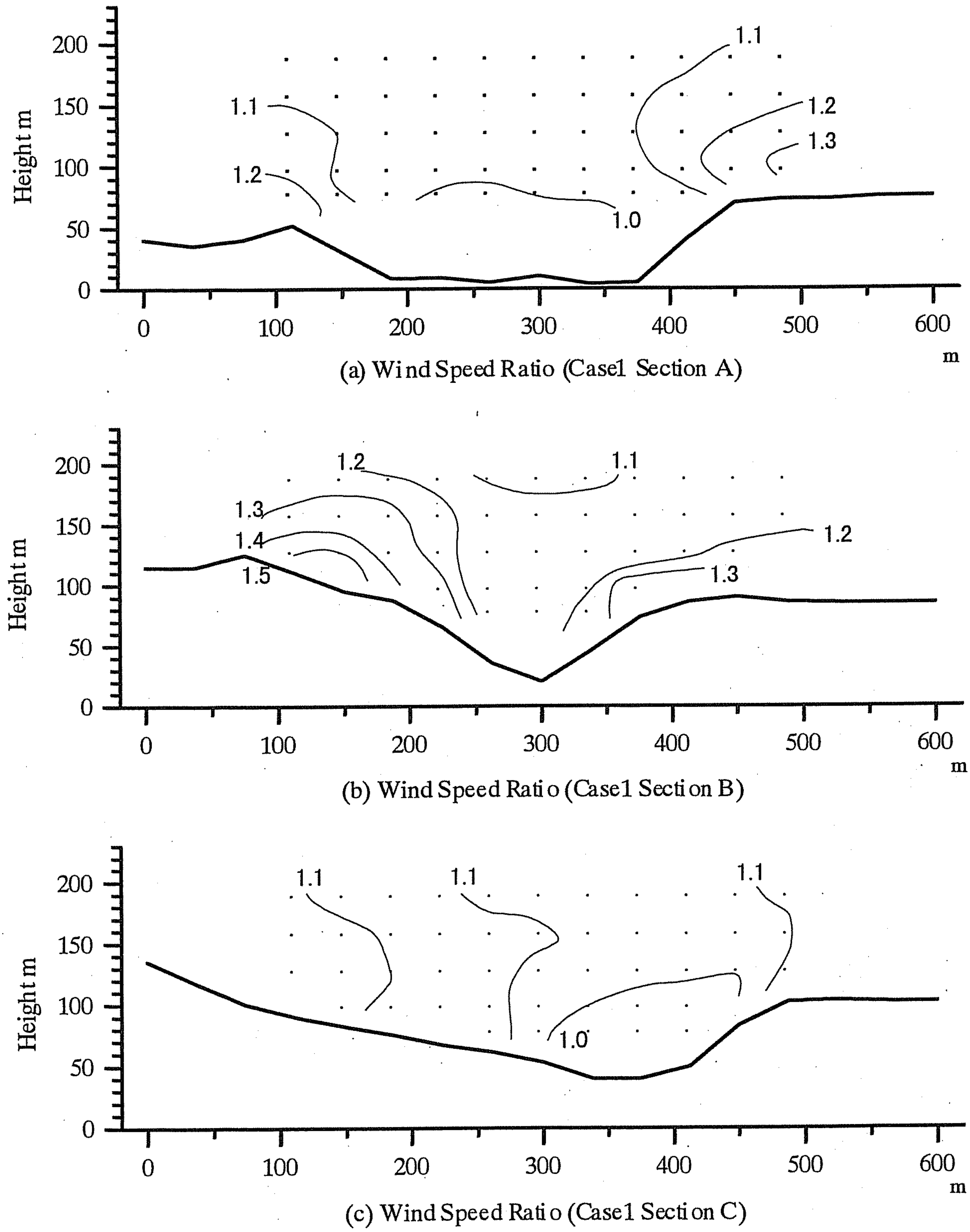


Fig. 7 Profile of Approaching Flow

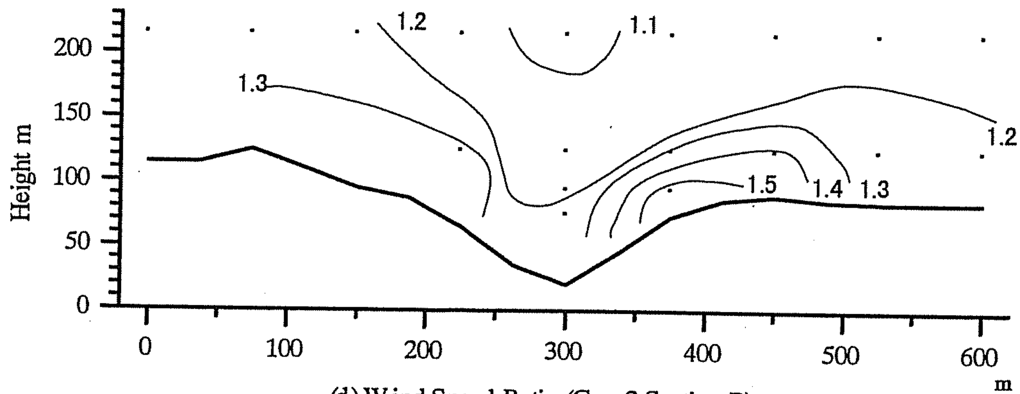


(a) Wind Speed Ratio (Case1 Section A)

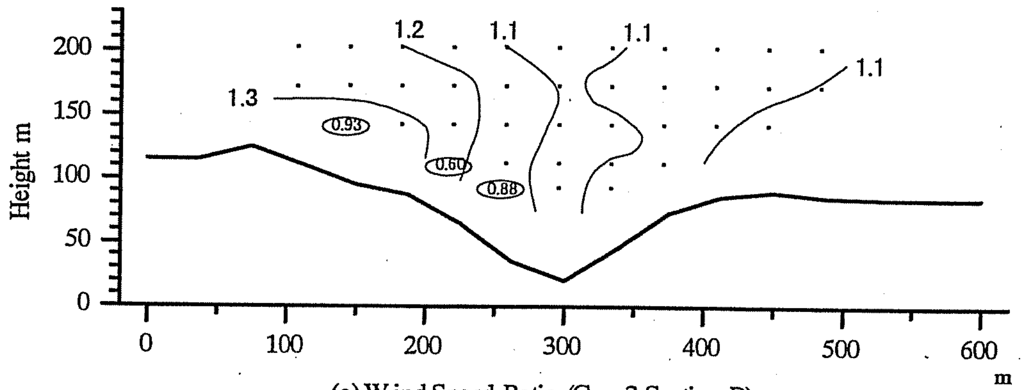
(b) Wind Speed Ratio (Case1 Section B)

(c) Wind Speed Ratio (Case1 Section C)

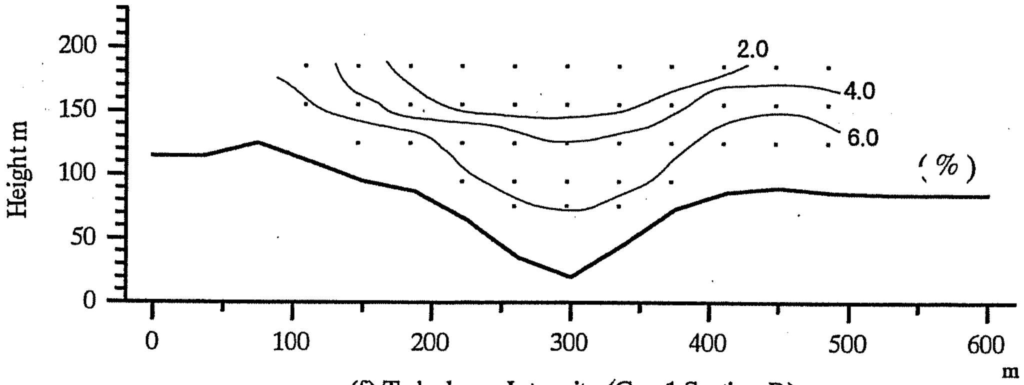
Fig.8 Results of Wind Tunnel Study for the Real Valley



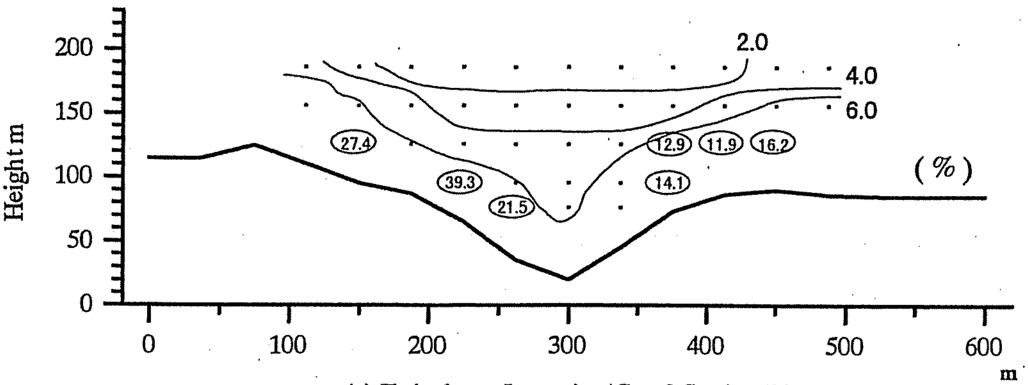
(d) Wind Speed Ratio (Case2 Section B)



(e) Wind Speed Ratio (Case3 Section B)



(f) Turbulence Intensity (Case1 Section B)



(g) Turbulence Intensity (Case3 Section B)

Fig. 8 Results of Wind Tunnel Test for the Real Valley (continued)

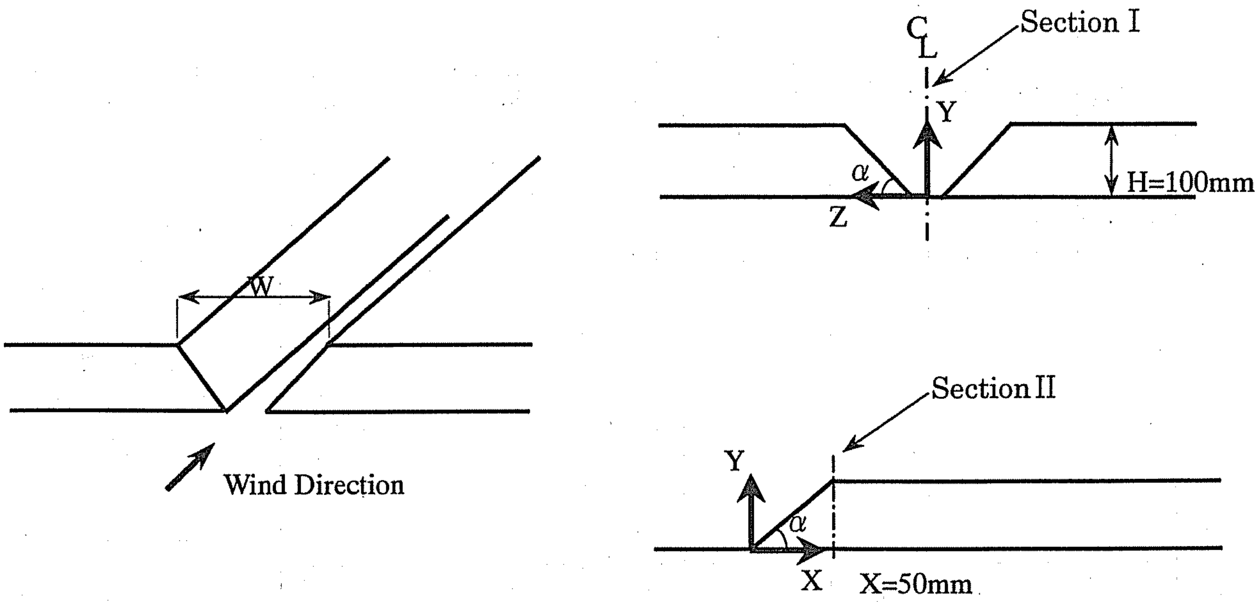


Fig.9 Simplified Valley Model

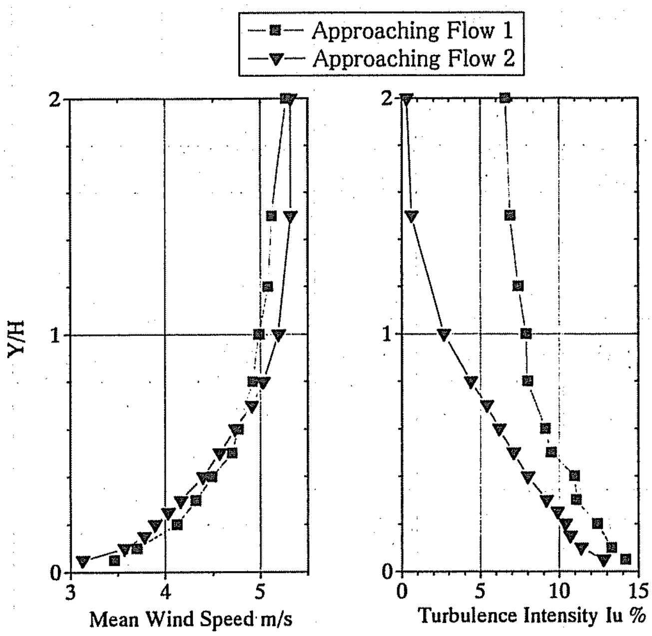
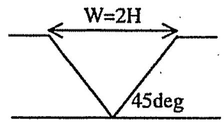
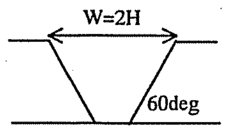
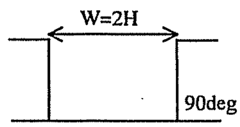
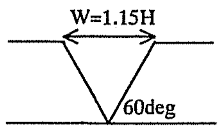
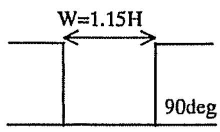
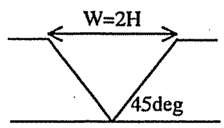
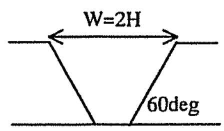
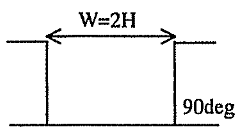


Fig. 10 Profile of Approaching Flow

Table 2 Wind Tunnel Study for the Simplified Valley

CASE	Approaching Flow	Width of Valley W	Slope Angle α (deg.)	Maximum Value of Wind Speed Ratio	Wind Speed Ratio *1	Minimum Value of Turbulence Intensity *2 (%)	Turbulence Intensity *1 (%)	Shape of Cross Section
1	1	W=2H	45	1.18	0.92	5.5	7.6	
2	1	W=2H	60	1.22	0.87	5.1	10.1	
3	1	W=2H	90	1.19	0.58	5.9	21.8	
4	1	W=1.15H	60	1.36	0.79	5.0	10.4	
5	1	W=1.15H	90	1.30	0.54	5.8	21.7	
6	2	W=2H	45	1.24	1.02	7.2	10.6	
7	2	W=2H	60	1.34	1.03	6.7	12.2	
8	2	W=2H	90	1.29	0.72	7.6	25.8	

*1 X=5.5H , Y=0.75H *2 Y=0.75H

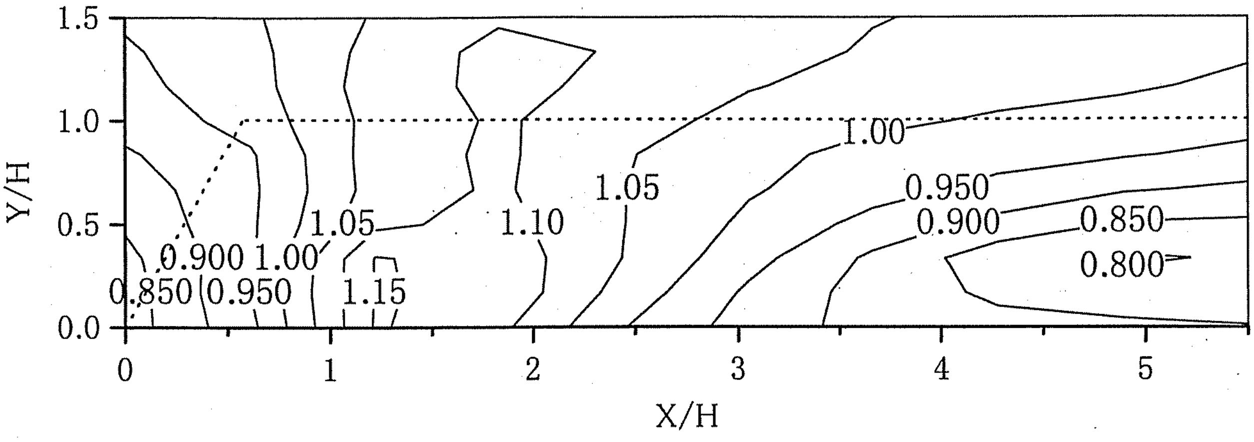


Fig.11 Distribution of Wind Speed Ratio (Case 2　Section I)

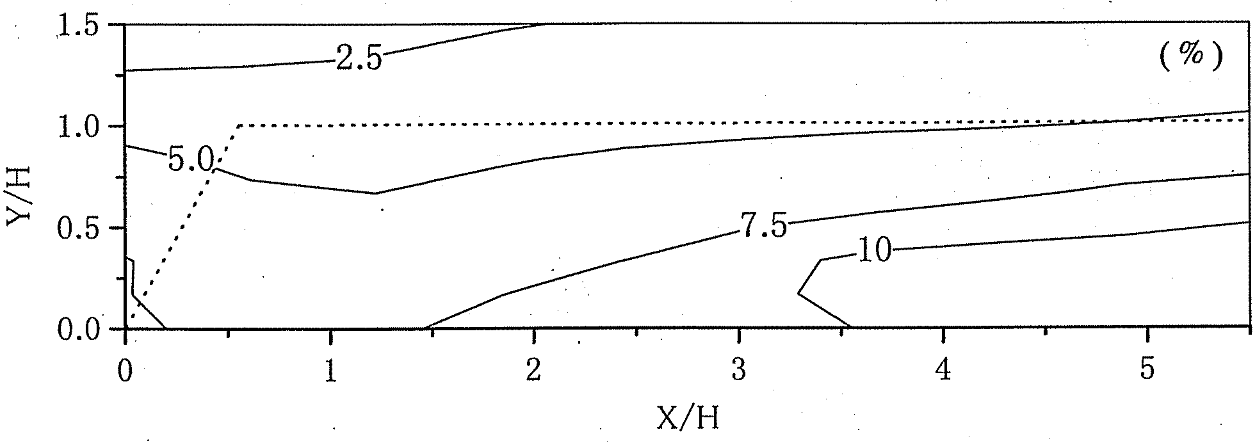


Fig.12 Distribution of Turbulence Intensity (Case 2　Section I)

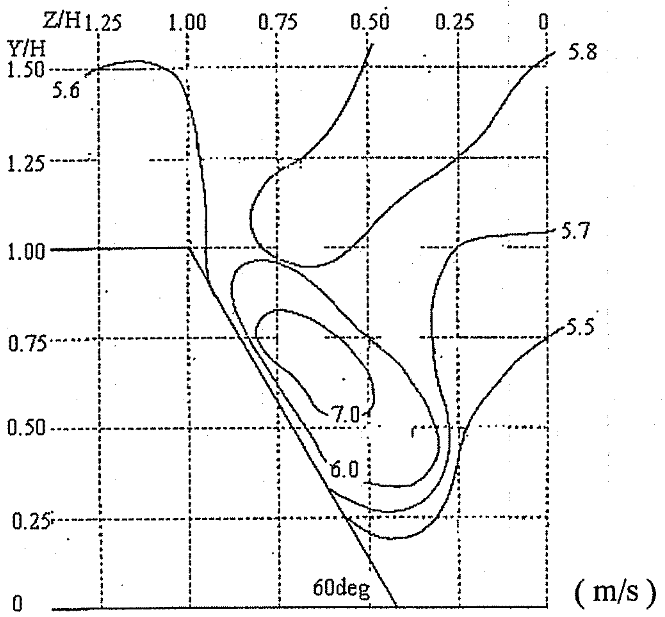
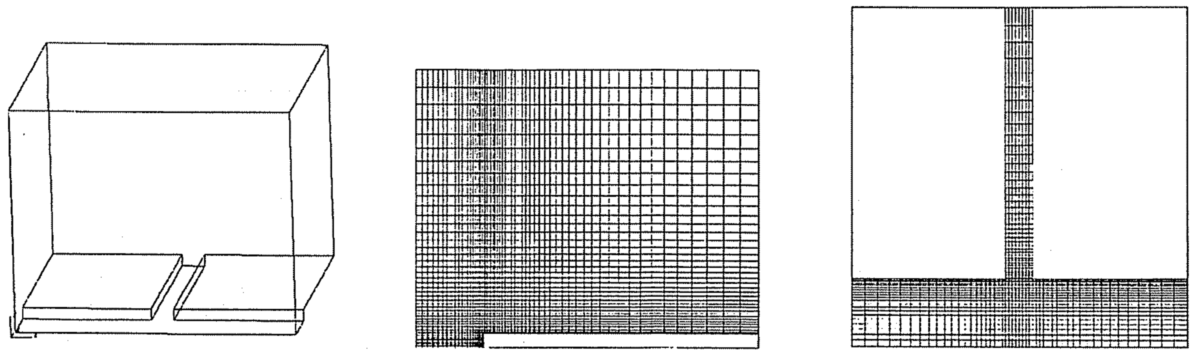


Fig.13 Distribution of Wind Speed (Case 2　Section II)



(a) Analysis Area (b) Mesh (XZ Section) (c) Mesh (XY Section)

Fig. 14 Analysis Area

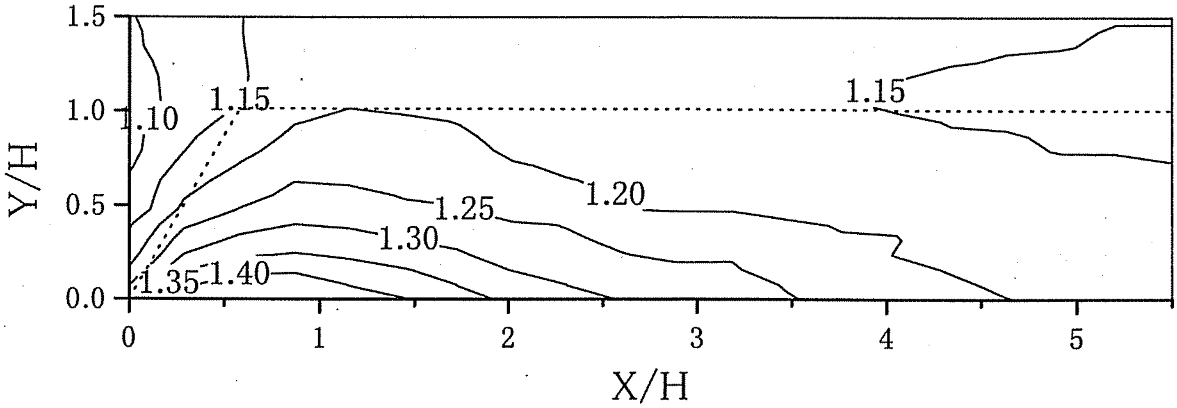
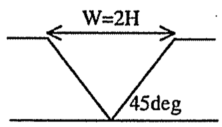
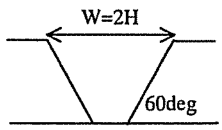


Fig. 15 Distribution of Wind Speed Ratio

Table 3 Results of CFD

CASE	Approaching Flow	Width of Valley W	Slope Angle α	Maximum Value of Wind Speed Ratio	Shape of Cross Section
1	1	W=2H	45	1.36	
2	1	W=2H	60	1.45	
3	1	W=2H	90	1.40