Volume I

Fluid Dynamics and Computational Modeling

Maria Forest

Fluid Dynamics and Computational Modeling Volume I

Edited by **Maria Forest**

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Preface

Over the recent decade, advancements and applications have progressed exponentially. This has led to the increased interest in this field and projects are being conducted to enhance knowledge. The main objective of this book is to present some of the critical challenges and provide insights into possible solutions. This book will answer the varied questions that arise in the field and also provide an increased scope for furthering studies.

This book contains updated information on topics like fluid dynamics, computational modeling and its applications, and aims to help scientists, engineers, and graduate students as a general reference. It discusses topics like: winds, building and risk prevention; multiphase flow, structures and gases; heat transfer, combustion and energy; medical and biomechanical applications; and other crucial topics. Along with all that has been mentioned, this book also gives a detailed view of computational fluid dynamics and applications, without excluding experimental and theoretical aspects.

I hope that this book, with its visionary approach, will be a valuable addition and will promote interest among readers. Each of the authors has provided their extraordinary competence in their specific fields by providing different perspectives as they come from diverse nations and regions. I thank them for their contributions.

Editor

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Part 1

Winds, Building, and Risk Prevention

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Study of Wind-Induced Interference Effects on the Fujian Earth-Buildings

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China

1. Introduction

As the only large-scale rammed-earth dwelling worldwide, Fujian earth-building gets much attention for its unique style, grand scale, ingenious structure, abundant cultural connotation, reasonable layout and the concept of keeping harmony with nature. In July 2008, Chuxi earth-building cluster, Hongkeng earth-building cluster, Gaobei earth-building cluster, Yangxiang Lou and Zhenfu Lou were listed among world heritage. They are important parts of Fujian earth-building with a long history, vast distribution, various types and rich connotation. Earth-building culture roots in oriental ethical relations and provides specific historical witness to traditional style of living by clansman, It is a unique achievement by employing rammed raw earth in large scale with "outstanding universal value".

Because of the high frequency of typhoon between summer and autumn in mountainous areas of the western Fujian, buildings in high and open areas often get serious damages, as shown in figure 1. In 2006, the 4th cyclone "BiLiSi" brought heavy damage to Daoyun Lou which is 400 years old. Six rooms in it collapsed, several tiles were blew off and the total number of damaged rooms reached more than 10. As one of the world cultural heritages, the protection, utilization and development of Fujian earth-building is the major issue to be deal with. Presently, the theory study for wind-resistant of low buildings is still not enough, the failure mechanism hasn't been studied thoroughly. For low buildings often appear in the form of groups, the related studies are even less. So research of wind interference effect in earth-building groups can not only fill the blank of research studies but also put forward some corresponding measures for protection of the world cultural heritage.

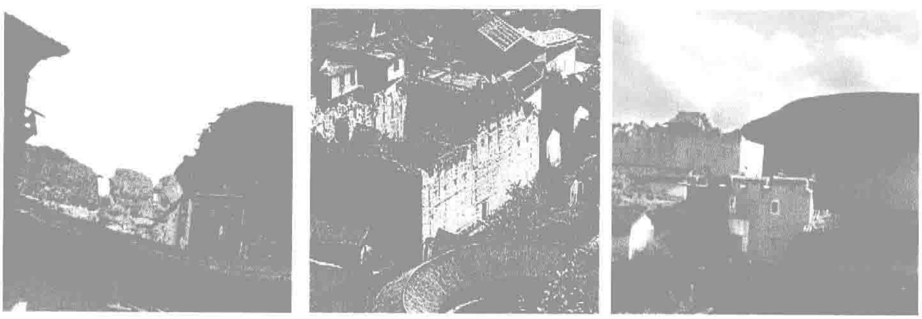


Fig. 1. Storm damage to the roof of earth-buildings

2. The influencing factors of wind interference effect

Fujian earth-buildings are often located in the form of groups, as shown in figure 2. Surface wind load is heavily influenced by the surrounding buildings and the main influencing factors include the height of the building, the relative position between buildings, section size and shape, the wind speed and wind direction, the type of wind field, etc.

Fig. 2. Tianluokeng earth-building cluster

2.1 The influence of landscape

Roughness of the landscape has a great influence on the structure wind loads, And under different wind, the interference effects between the buildings are quite different from the wind. Compared to the isolated building at the open area, Walker and Roy[1] found that the average load, peak load and bending moment are increased in the urban area of wind load. Under the open countryside and suburban areas of different topography, Case. P.C [2] study on the transient external pressure of the gable roof building experimental. He pointed out that wind load at buildings in the city suburbs is lower than that in the open landscape. And the arrangement of groups help reduced the load on a single. Blessmann[3] studied variety of landscape effects of wind interference, The results show that the moderating effect of the open landscape is most evident. Because of the turbulence is relatively low in open landscape, The pulse of wake in the upstream building has a strong correlation, Therefore, wind loads on downstream buildings caused by increased.

2.2 The influence of building's width and height

The width of the windward side of the housing has great influence on eddy size behind the leeward side, And the size of the upstream building construction also affect the downstream response of wind interference. Taniike[4] study the Wind-induced interference effects under low turbulence contour and different section size in square columns, He pointed out that the average wind load to the along wind will decline with the increase size of upper building's section, and that dynamic response to the along wind will increase with increasing section width. Under normal circumstances, when the height of adjacent buildings is equal to or greater more than half of the height of the building, we should take into account the mutual interference effects between groups, and ignoring the interference of the building which less than half the height of buildings[5].

2.3 The influence of number of buildings

In previous tests of wind interference, we remain in the interference effect between two buildings for a long time, and rarely consider the interference effects between more than three buildings. Professor Xiezhuangning[6] studied the wind-induced disturbance response between the three buildings, and analysis the interference of the characteristics and mechanism by neural networks, spectral analysis and statistics. The results show that the combined effects of the two buildings would be stronger than a single building. Under the landscape of Class B, Interference factor of two buildings would be increased more than 79% of a single building.

2.4 The influence of spacing of building group

Holmes[7] study the wind characteristics of the street on both sides of the building, and found upstream of the shadowing effect and the building construction the distance between a great relationship. Zhao qingchun[8] have studied the low gable roof wind-induced interference effect, found group effect on the windward roof pressure front and rear degree of influence. When the workshop's distance was 2b the interference obviously. The wind tunnel experiments show that: when buildings adjacent cross-wind side by side, the gap flow effect presence in the region when $S / D \leq 2$,(S for the building spacing, D for the side of building); When Buildings are along the windward, shielding effect exists in $S / D \leq 3$ regions.

2.5 The impact of the wind stream

Tsutsumi,J.[9]conducted a model test in different wind direction of wind load characteristics of the group, received the average wind pressure coefficient of the windward and leeward of buildings' surface. Compare and analyze the model's average wind pressure coefficient under different architectural layout, Get the average wind pressure coefficient varies with the change of wind direction. Generally speaking, the flow separation zone will increased by the skew wind, air disturbance will more severe, and the flow will become more complex.

3. Analysis of wind interference effect between two Earth-buildings

3.1 Calculation model

Fujian earth-building is ring-shaped with one-ring building or more. Here we simplify the model with ignoring the hallway, ancestral temple and such subsidiary structures. In the study of wind-induced interference, we select the typical circular earth-building to do the numerical simulation. The diameter of the biggest circular earth-building is 82 meters and the smallest is 17 meters while the common number of stories is 2 ~ 4 [10]. The research model this article selects is 28 meters in diameter, 3 layers, 11.2 meters high and under conditions as shown in fig. 3. This chapter mainly studies the characteristics of wind load and the air flowing field of circular earth-buildings, the change rule under different spacing of which are also explored.

Here we major change the windward spacing between two earth-buildings and wind direction, as shown in fig.03. S stands for spacing between two earth-buildings, D stands for horizontal scale (the diameter of the bigger circular earth-building), n is valued respectively by 0.15, 0.5, 0.75, 0.25, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0. The characteristics of Fujian earth-buildings are: clay wall, general 1-m ~ 1.5 m of wall thick, chines-style tile roof and big pick eaves. When typhoon comes, the big pick eaves are most easily swept away, leading to the damage of whole roof structure. Therefore, the roof zoning plan of the research object (i.e. the disturbed body) is shown in figure 4. The dividing is in a counterclockwise direction and the roof is divided into eaves part and ridge part. The upper surface of outside carry eaves are signed respectively by WTS1 ~ WTS8, the lower surface by WTX1 ~ WTX8. The upper surface of inside carry eaves are signed respectively by NTS1~ NTS8, the lower surface by NTX1 ~ NTX8. The ridge part is divided into the inside part and outside part, and they are signed respectively by NJ1~ NJ8 and WJ1~ WJ8.

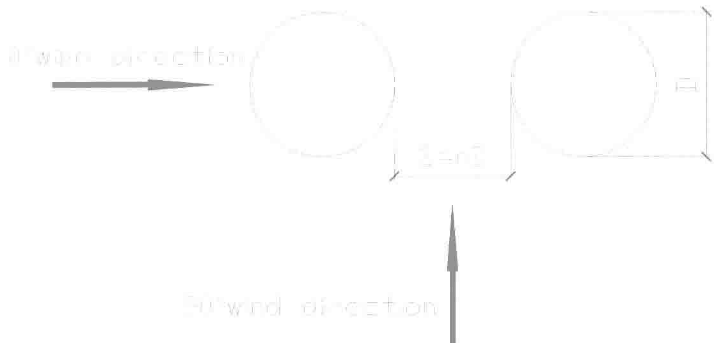


Fig. 3. Plan of Earth-building and wind direction

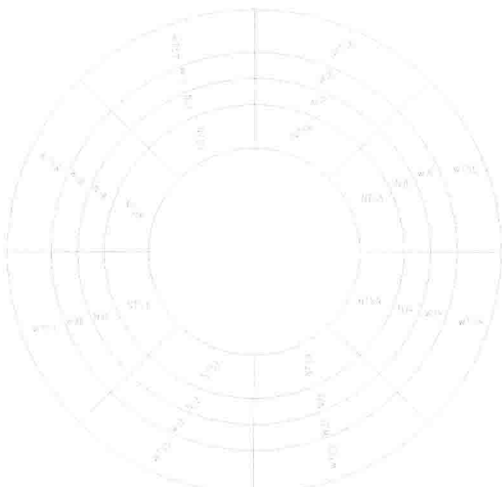
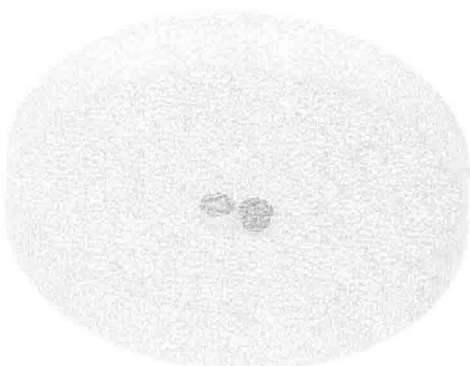


Fig. 4. Roofing zoning

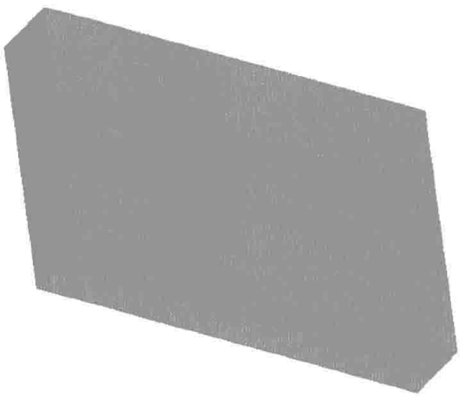
Settings of basic parameters in numerical simulation: according to reference literatures[11], domains' size can be set as following: B×L×H=600m×500m×100m, its blocking rate is 0.6%, meets requirements. As shown in figure 5, the whole calculation domain is divided into two parts: internal area and external area. The cylinder with 380m diameter is the internal area-domain 1, the other part is external area-domain2. Domain 1 use the tetrahedron meshes while domain 2 adopts convergence higher structured hexahedral meshes. Fujian Earth-building is located in rural mountain areas , h_0 =10m, v_0 =5.35m/s, Fujian Earth-building area belongs to the class B landform, roughness index α =0.16. Turbulence intensity I(z)=0.194, turbulence integral scale Lu =60.55m,kinetic energy k(z) and dissipation rate ε(z) are adopted as the following form:

$$\begin{cases} k(z) = 0.5 \times [I(z) \times \bar{u}(z)]^2 \\ \varepsilon(z) = \dfrac{4C_\mu^{3/4} k(z)^{3/2}}{KL_u} \end{cases} \tag{1}$$

The surface of buildings use non-slip wall, the two sides and top surface of the numerical wind tunnel use free gliding wall, the outlet of the numerical wind tunnel use open pressure export. This paper argues turbulence is fully development (The static pressure is zero). Turbulence model adopt shear stress transport model (SST $k-\omega$ model).



(a) Meshing of internal domain 1



(b) Meshing of internal domain 2

Fig. 5. Meshing of domain

3.2 Analysis of wind characteristic

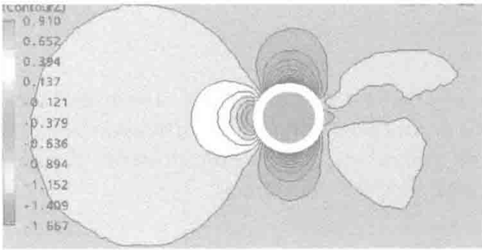
This paper adopt every 45° wind direction to do wind interference analysis, for symmetry of the structure, three conditions were simulated in this paper under the same spacing. This paper analyzed wind pressure coefficient at local wind vector at Earth-building 2/3 highly level profile and centre vertical profile, and contrasted wind pressure coefficient between monomer Earth-building and group Earth-building

3.2.1 0° wind direction

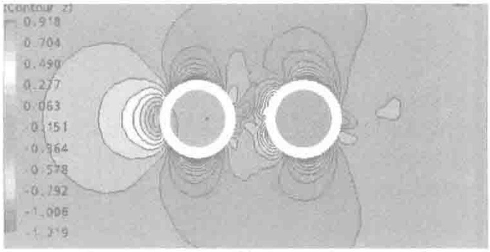
At the windward area, flow has a positive stagnation point at 2/3 highly level profile, from the stagnation point airflow radiate outward[9]. At the area above the point, the current rise upward and beyond Earth-building roof top; at the area below the point, airflow downward and flow to the ground. So this paper choose 2/3 highly level profile to discuss the wind field characteristics. Meanwhile, this paper select of center vertical profile as features surface, analyze flow field characteristics between Earth groups Building through the observation of wind pressure coefficient graph of this vertical profile.

(1) Level cross section at 0° wind direction

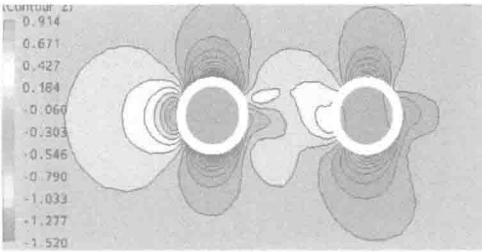
Fig. 6 shows the isocline of the air pressure coefficient at 2/3 highly level profile. From Fig 6(a) we can see the isocline wind pressure coefficient is very plump at the windward area and the two sides of single building. Wind pressure coefficient is positive in the windward,



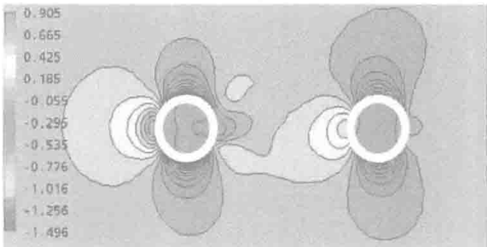
(a) Wind pressure coefficient of cross section of single building



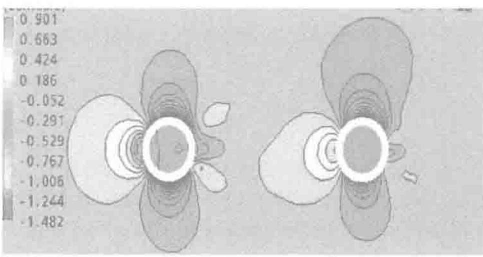
(b) Wind pressure coefficient of cross when S=0.15D



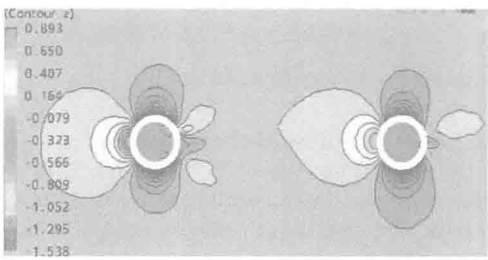
(c) Wind pressure coefficient of cross section when S=0.75D



(d) Wind pressure coefficient of when S=1.5D



(e) Wind pressure coefficient of cross section when S=2.0D



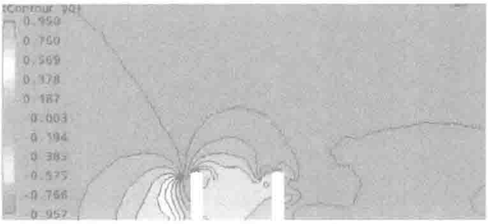
(f) Wind pressure coefficient of cross when S=3.0D

Fig. 6. Wind pressure coefficient of 2/3highly level profile at 0 ° wind direction

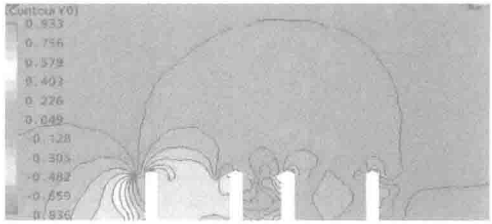
and the closer to the building, the bigger it is. While this coefficient is negative in the side, and the closer to the building, the bigger the absolute value is. But in the leeward surface, we can see two air pressure coefficient equivalent envelope for the two vortexes formed at leeward. Figure 6 (b) is air pressure coefficient graph of two spacing is 0.15 D circular Earth-building. Due to the distance between the two buildings smaller, flow between the two buildings is more complex. Air pressure coefficient isocline mutual surrounded relatively intense, and the value has reduce trend. Which is especially noteworthy is the wind pressure coefficient isocline of perturbation building is quite different to monomer at windward direction; it appears two isocline large regions. The interfered building is affected by two vortexes at the tail of the front Earth-building. When the spacing is 0.75 D, vortex is gradually developed, air pressure coefficient isocline between two Earth-buildings is linked together, and mutual interference is still evident. When the spacing is 1.5 D, the whirlpool basically develops fully and the isocline is tending to independence. When the spacing continues to increase to 3.0 D, development of whirlpool is fully, air pressure coefficient isocline around two Earth-buildings is full independence and tend to monomer conditions. At 0 ° wind direction, generally speaking, flow field of downstream Earth-building changes greatly, downstream Earth-building under the more obvious influence.

(2) Center vertical profile of 0 °wind direction

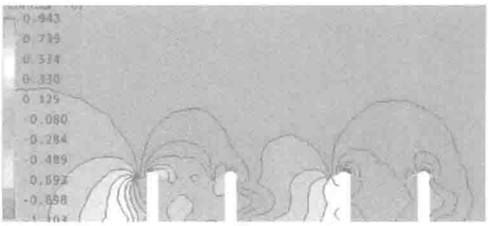
Figure 7 gives wind pressure coefficients isocline of center vertical profile in different spacing.



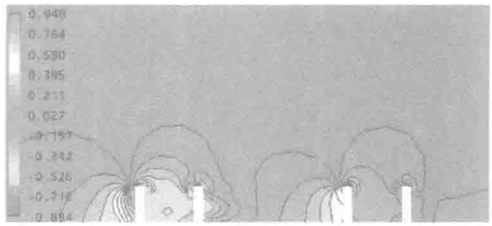
(a) Wind pressure coefficient of center vertical vertical profile



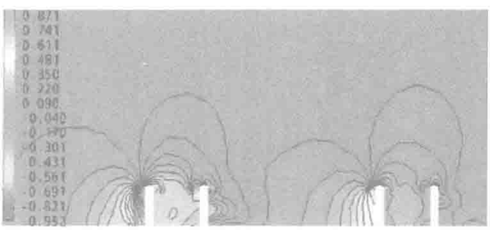
(b) Wind pressure coefficient of center vertical profile when S = 0.15D



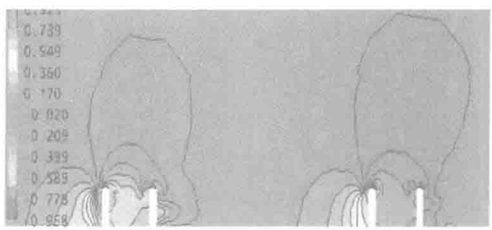
(c) Wind pressure coefficient of center vertical profile when S = 0.75D



(d) Wind pressure coefficient of center vertical profile when S = 0.75D



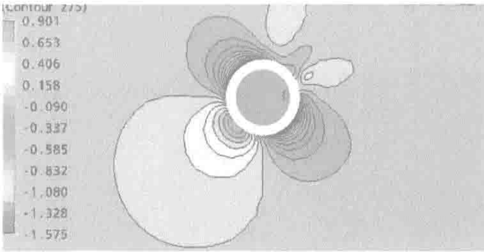
(e) Wind pressure coefficient of center vertical profile when S = 2D



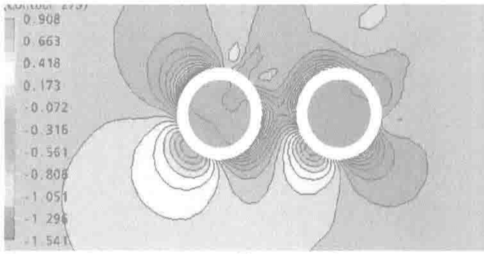
(f) Wind pressure coefficient of center vertical profile when S =3D

Fig. 7. Wind pressure coefficient of central vertical profile of 0 ° wind direction

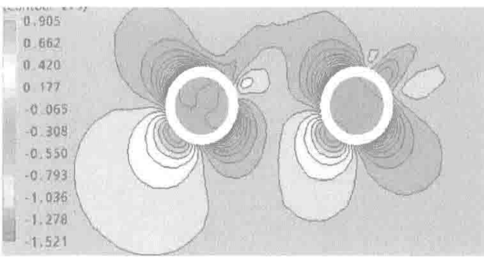
From figure 7 we can see that wind pressure coefficients of Earth-buildings center vertical profile are similar with one, when spacing for 3.0 D. Wind pressure coefficients isocline appear separation phenomenon is quite serious in the external roofs, where the separation point expose many isocline. Under the surface of wind pressure coefficients significantly greater than upper one, which above is negative, the other is positive in the external roofs. Wind pressure coefficients of upper and under surface is close in the external roofs, wind pressure coefficients of upper and under surface almost to zero in the internal roofs, when they are in the leeward flow fields. When both ones spacing is 0.15 D, The prevailing wind direction of wind field and leeward are significantly different, the prevailing flow fields is not affected, and drafting leeward surface whirlpool didn't develop completely Because of the stop function behind Earth-buildings. Whirlpool gradually development, Earth-buildings mutual interference slowly reduce, as spacing is increasing, finally wind field becomes into a monomer.



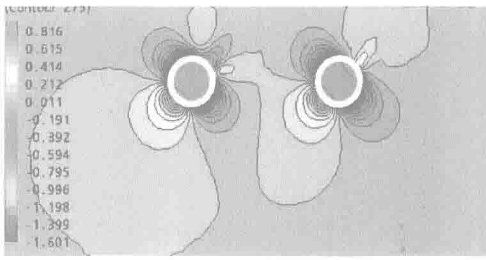
(a) Wind pressure coefficient of cross section of single building



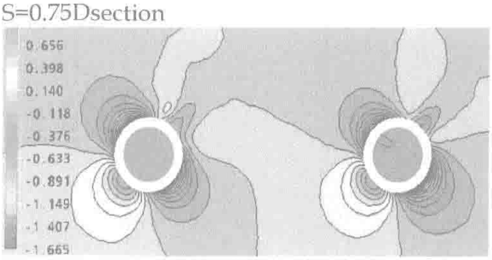
(b) Wind pressure coefficient of cross section when S=0.15D



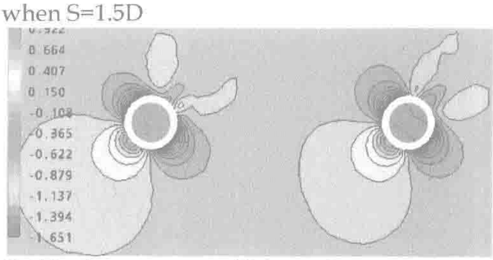
(c) Wind pressure coefficient of cross when S=0.75Dsection



(d) Wind pressure coefficient of cross section when S=1.5D



(e) Wind pressure coefficient of cross section when S=2.0D



(f) Wind pressure coefficient of cross section when S=2.0D

Fig. 8. Wind pressure coefficient of 2/3highly level profile at 45 ° wind direction

3.2.2 45° wind direction

(1) Level cross section of 45°wind direction

Figure 8 45°wind direction is given level of the wind pressure coefficients cross section in 2/3 housing height place, we can see that Earth-buildings wind field changes significantly around in different wind direction for monomer Earth-building, the situation is similar with above, here is not to say much. For two Earth-buildings speaking, when spacing is 0.15 D, oblique flow fields makes Earth-buildings both sides have larger wind speed, but it is affected behind Earth-buildings, wind pressure coefficients isocline have inter-permeation by each other, and is very strong between two Earth-buildings wind pressure isocline with monomer markedly different in two Earth-buildings adjacent area and leeward surface for the front of Earth-buildings, drafting produces whirlpool is impeded, which leading to wind pressure coefficients reduce, and most regional present negative, interference phenomenon is seriously in the leeward surface Earth-buildings also wind pressure isocline with monomer markedly different in two Earth-buildings adjacent area and leeward surface for Behind Earth-buildings, but wind pressure changes very little in lateral area.
When the spacing becomes larger between two Earth-buildings, and from spacing 0.75D to 2.0D, with drafting place whirlpool developed slowly in the front of Earth-buildings, wind pressure coefficients isocline tend to be independent, interference become weak. When spacing for 3.0 D, interference has not obvious, the flow fields around the Earth-buildings is similar with monomer.

(2) Center vertical profile of 45 ° wind direction

In figure 9, 45° wind direction are given under different spacing vertical section center air pressure coefficient isocline map, From figure 9 (a) which can be seen, air pressure coefficient value of Earth-buildings in the windward side is lesser and negative, near the Earth-buildings metopic air pressure coefficient absolute value increases, in the outside carry eaves, separated phenomenon of air pressure coefficient appeared .It's all negative value in fluctuation pick eaves. Both internal and external roof are affected by negative pressure, and the internal roof endure a bigger negative pressure. The leeward side is in negative pressure area, because of the blocking by Earth-buildings windward surface, wind pressure reduced. Fluctuation pick eaves pressure coefficients of the inside carry eaves are all negative value which offset each other. Outside carry eaves fluctuation surface wind pressure coefficient size differ not quite, the most air pressure coefficient negative value appeared in the leeward side metopic place. If both earth-buildings exist together, the mutual influence is obvious. In figure 9 (b) the spacing is 0.15D, Between two Earth-buildings regional wind pressure isocline showed great difference when monomer, between two Earth-buildings it has even been inter-permeation phenomenon, Behind Earth-buildings air pressure coefficient value in the windward side is negative and its absolute value increases of the monomer Earth-building. It shows that when two Earth-buildings interact with each other, the buildings in the downstream are in the area of architectural drafting upstream effect . The influence of its surface is opposite bigger. As spacing increase, center profile around two earth-buildings distributions of air pressure mutual interference gradually decreased, and change contour tend to monomer condition. When spacing is 3.0D, wind pressure coefficient changes contour line in center vertical of Earth-buildings is similar with monomer condition.