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

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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 $S / D \le 2$,(S for the building spacing, D for the side of building); When Buildings are along the windward, shielding effect exists in $S / D \le 3$ 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.

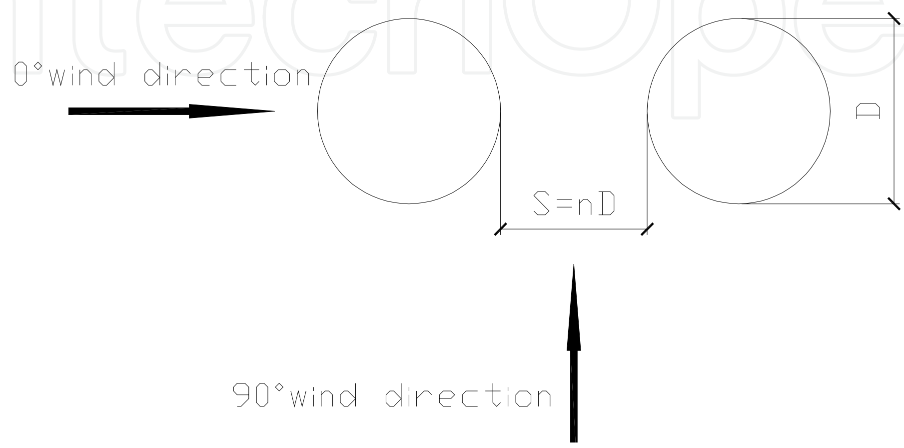


Fig. 3. Plan of Earth-building and wind direction

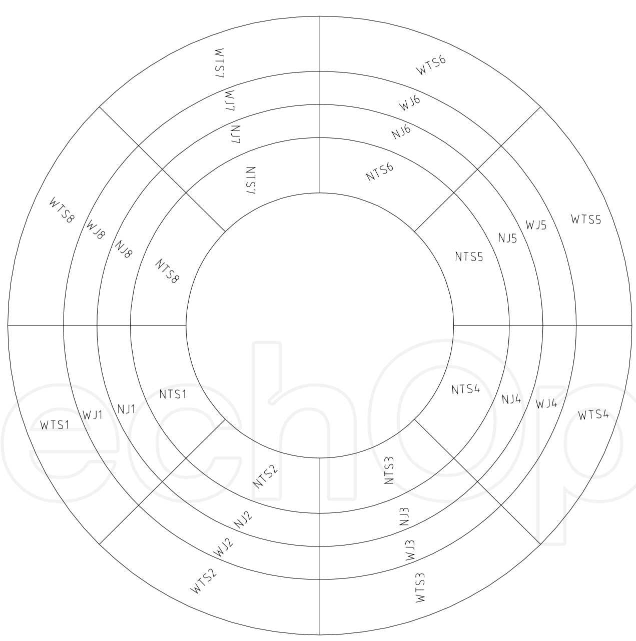
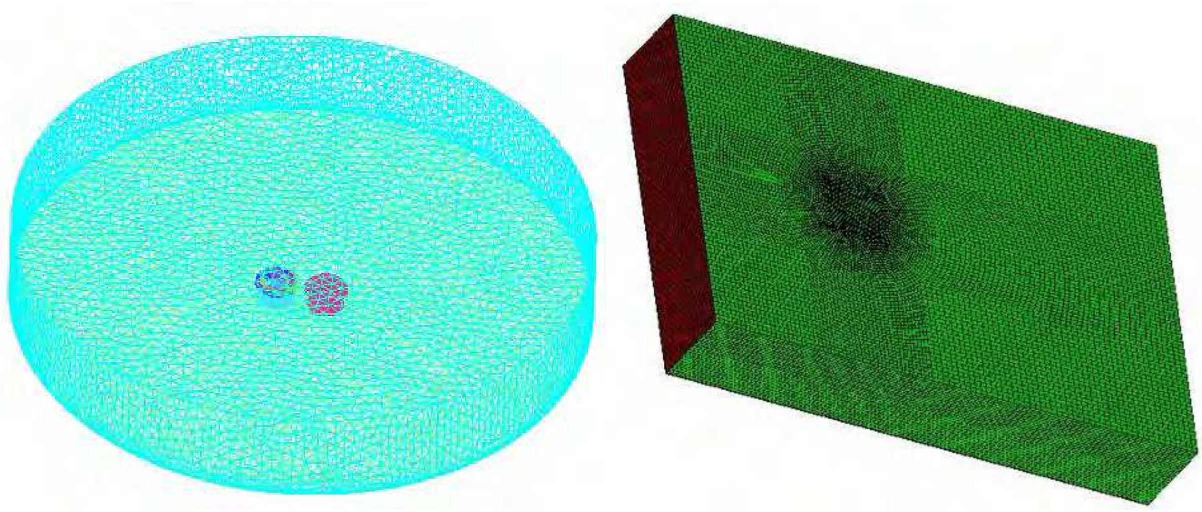


Fig. 4. Roofing zoning

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:

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

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

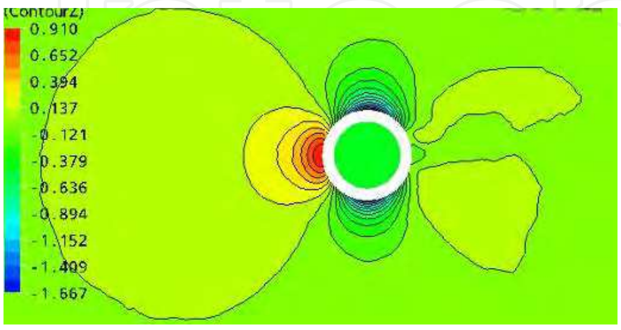
This paper adopt every 45° wind direction to do wind interference analysis, for symmetry of the structure, three conditions were simulated in this paper under the same spacing. This paper analyzed wind pressure coefficient at local wind vector at Earth-building 2/3 highly level profile and centre vertical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

3.2.1 0° wind direction

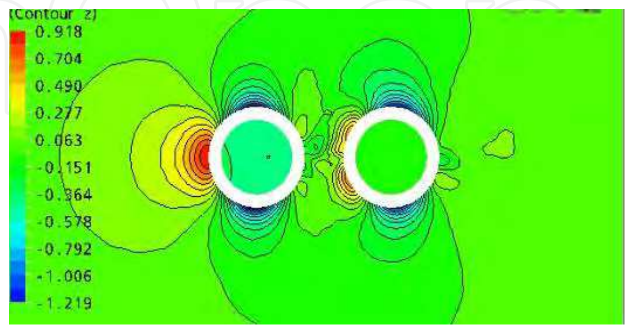
At the windward area, flow has a positive stagnation point at 2/3 highly level profile, from the stagnation point airflow radiate outward[9]. At the area above the point, the current rise upward and beyond Earth-building roof top; at the area below the point, airflow downward and flow to the ground. 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

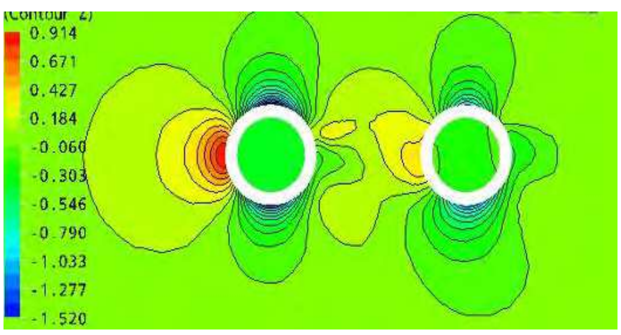
Fig. 6 shows the isocline of the air pressure coefficient at 2/3 highly level profile. From Fig 6(a) we can see the isocline wind pressure coefficient is very plump at the windward area and the two sides of single building. Wind pressure coefficient is positive in the windward,



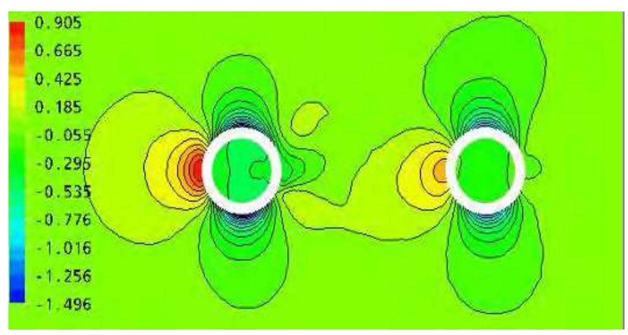
(a) Wind pressure coefficient of cross section of single building



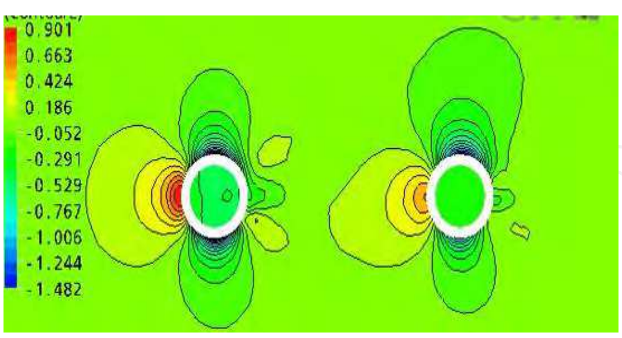
(b) Wind pressure coefficient of cross when S=0.15D



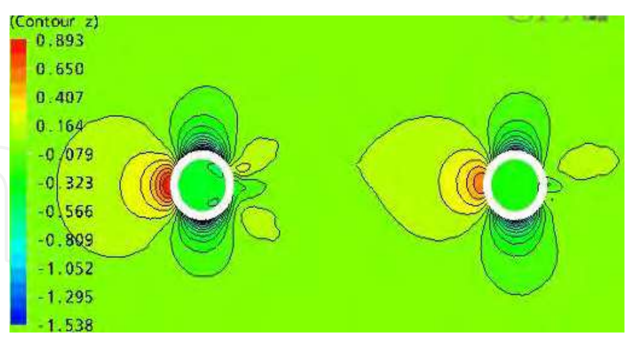
(c) Wind pressure coefficient of cross section when S=0.75D



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



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



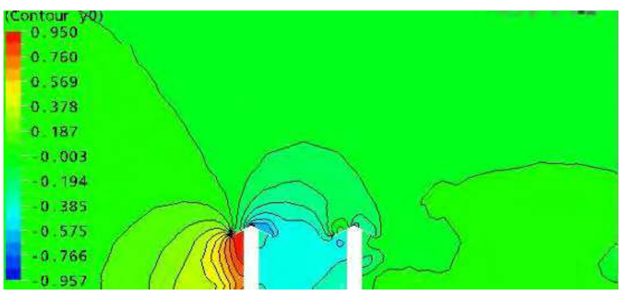
(f) Wind pressure coefficient of cross when S=3.0D

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

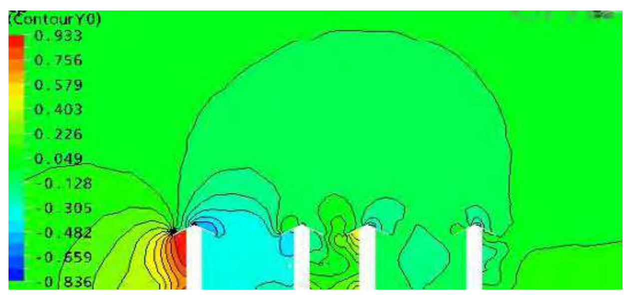
and the closer to the building, the bigger it is. While this coefficient is negative in the side, and the closer to the building, the bigger the absolute value is. But in the leeward surface, we can see two air pressure coefficient equivalent envelope for the two vortexes formed at leeward. Figure 6 (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

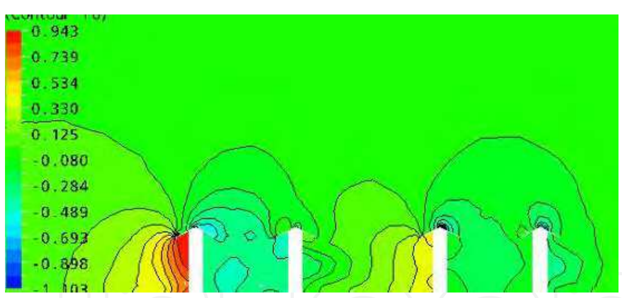
Figure 7 gives wind pressure coefficients isocline of center vertical profile in different spacing.



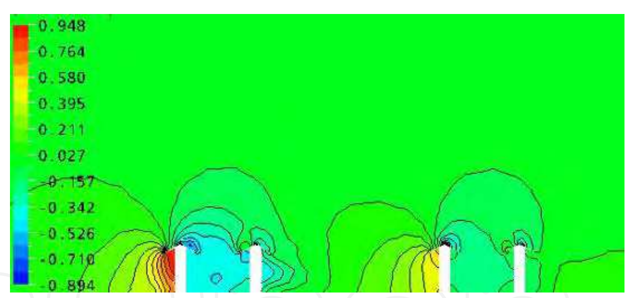
(a) Wind pressure coefficient of center vertical vertical profile



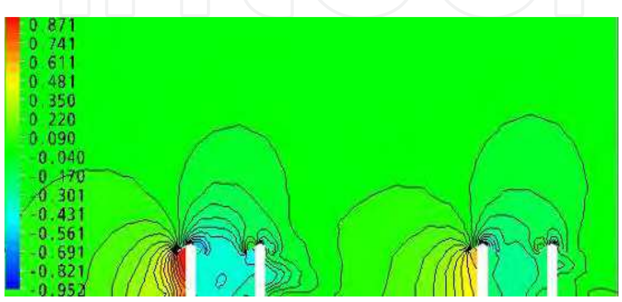
(b) Wind pressure coefficient of center vertical profile when S = 0.15D



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



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

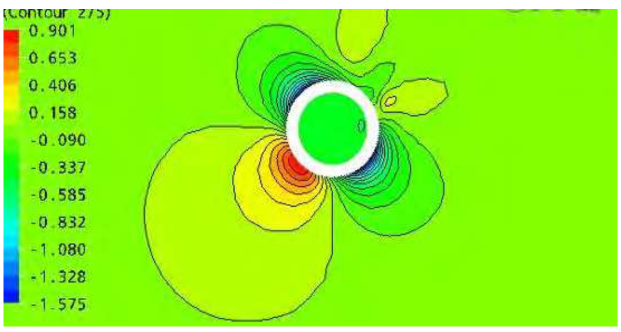


(e) Wind pressure coefficient of center vertical profile when S = 2D

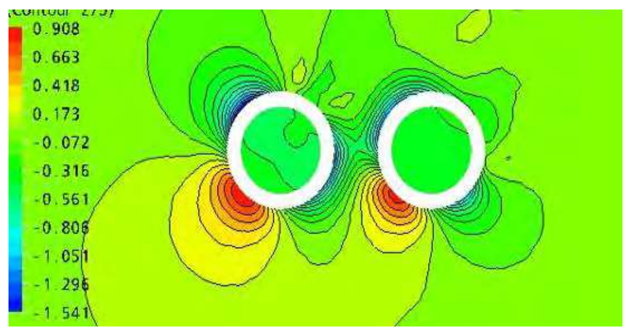
(f) Wind pressure coefficient of center vertical profile when S =3D

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

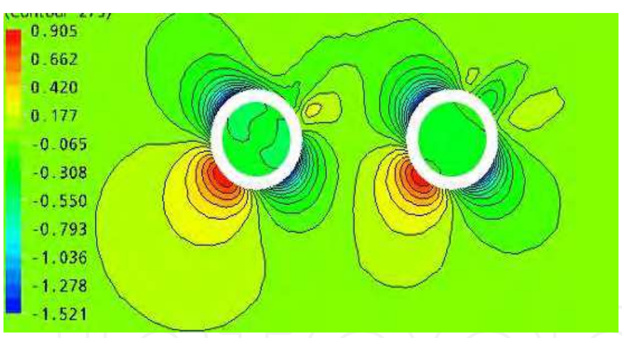
From figure 7 we can see that wind pressure coefficients of Earth-buildings center vertical profile are similar with one, when spacing for 3.0 D. Wind pressure coefficients isocline appear separation phenomenon is quite serious in the external roofs, where the separation point expose many isocline. Under 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.



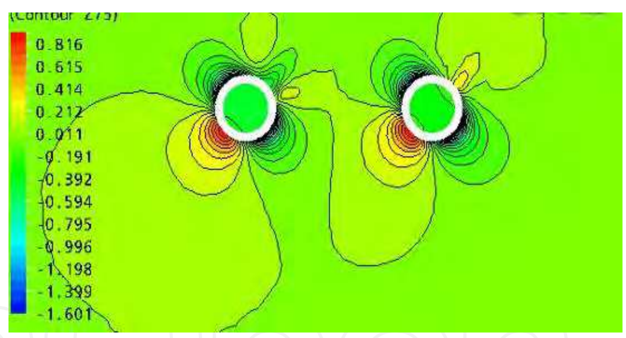
(a) Wind pressure coefficient of cross section of single building



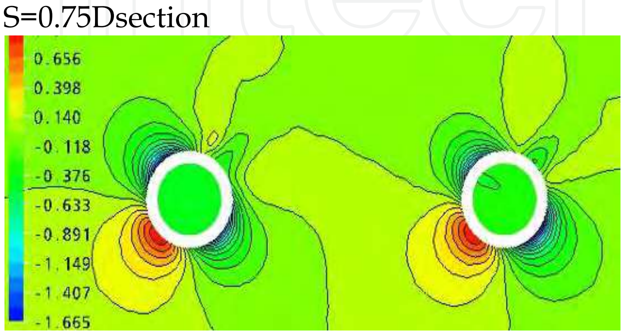
(b) Wind pressure coefficient of cross section when S=0.15D



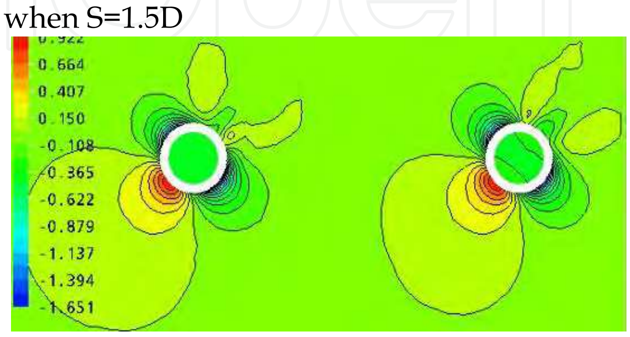
(c) Wind pressure coefficient of cross when S=0.75Dsection



(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

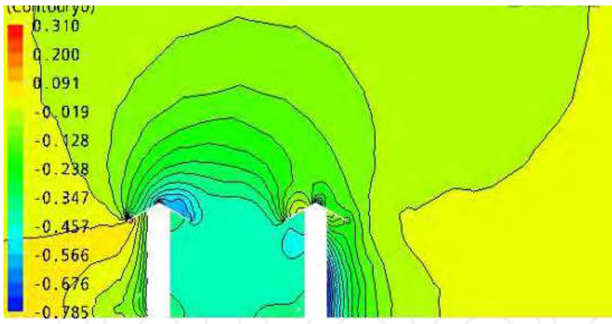
(1) Level cross section of 45°wind direction

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.

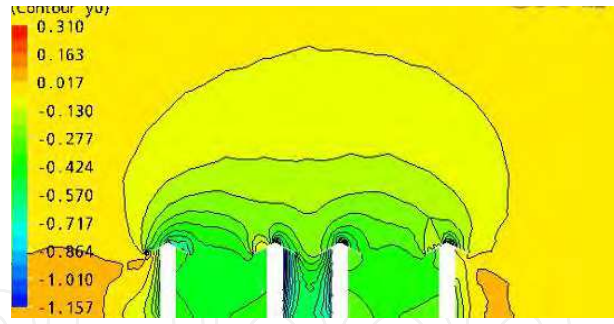
When the spacing becomes larger between two Earth-buildings, and from spacing 0.75D to 2.0D, with drafting place whirlpool developed slowly in the front of Earth-buildings, wind pressure coefficients isocline tend to be independent, interference become weak. When spacing for 3.0 D, interference has not 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.

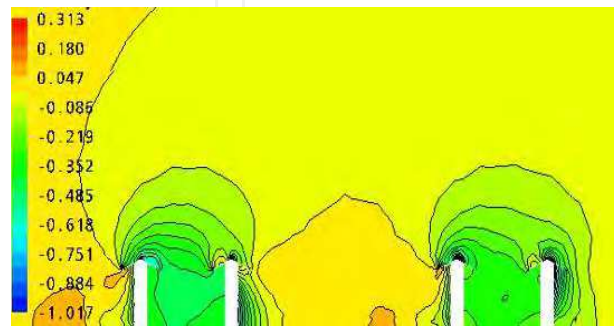


(a) Wind pressure coefficient of center profile of single building

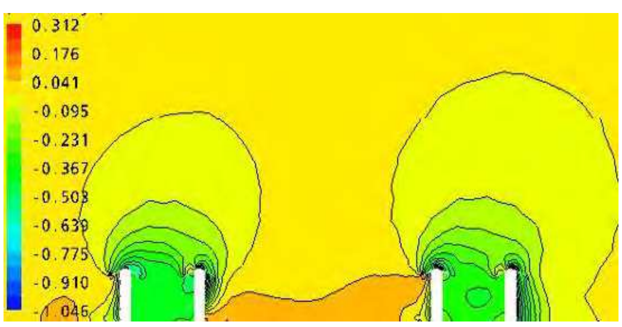


(b) Wind pressure coefficient of center vertical vertical profile when S = 0.15D

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



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



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

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

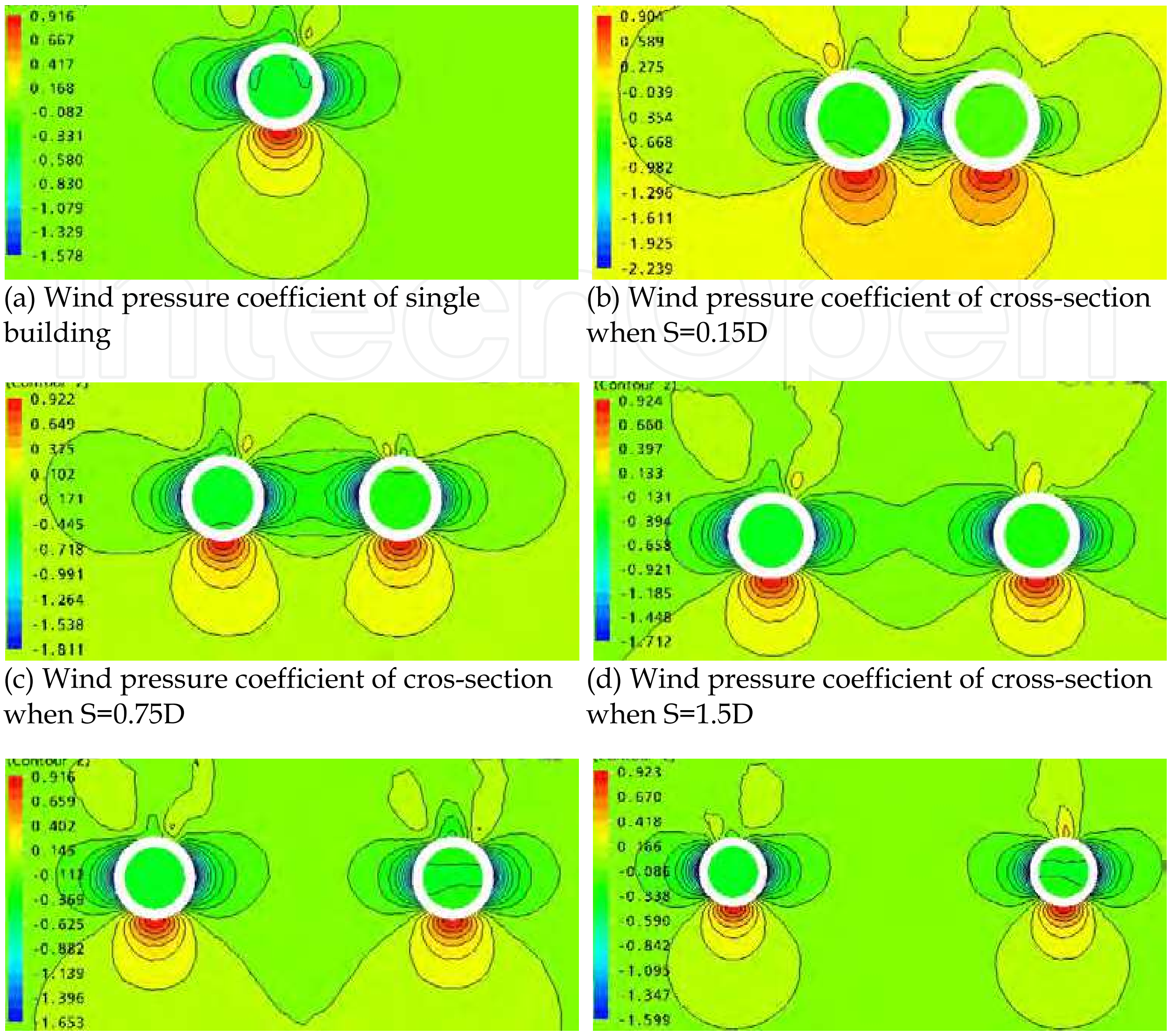
Fig. 9. 45° direction Angle of wind pressure coefficient vertical profile central figure

3.2.3 90° direction angle

Suppose define 0° direction angle as serial, adobe layout 45 ° direction angle is inclined column, then 90° direction angle, think adobe arrangement as coordination. Through the previous analysis, we know that , with the increasing distance, mutual interference will gradually decrease, buildings' field which surround by also tend to flow around the single Earth-building conditions.

(1) Level cross section of 90°wind direction

From Figure 10 (a),we can see that in 2/3 single adobe houses at the height of the level of cross-section of the wind pressure coefficient contour maps is same with 0° wind direction, on the windward side and side lines are full, the wind pressure coefficient is positive for integrity, and the more close from the adobe metopic walls ,the greater the pressure



(a) Wind pressure coefficient of single building

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

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

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

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

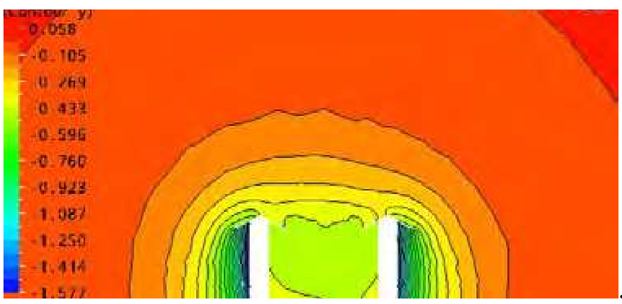
(f) Wind pressure coefficient of cross-section when S=3.0D

Fig. 10. Wind pressure coefficient of 2/3highly level profile at 45 ° wind direction

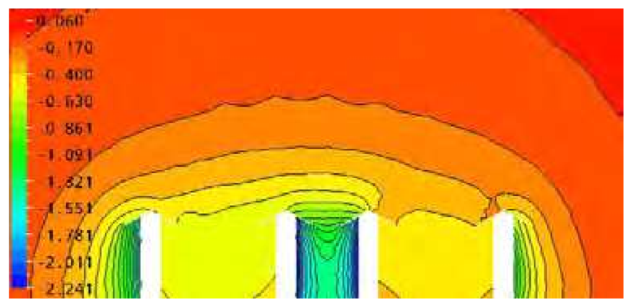
coefficient in the adobe negative side, the greater the closer the absolute value of the earth-building wall, or even 1.5.But in the leeward surface, due to the drafting place formed two swirls, we can see two wind pressure coefficient equivalent envelope. When there are two circular Earth-buildings, the spacing is 0.15 D according to figure 10 (b), air flow are the prevailing wind direction, due to shunt bypass side collision between the smaller ones, adobe air spacing interaction, air pressure coefficient negative, and absolute 2.239, at maximum achieve isocline wind pressure coefficient, and mutual surrounded relatively intense numerical more monomer adobe has the tendency of increase. Along with the increasing of the spacing distance, two 0.75 D adobe air pressure coefficient between each other 1.811, to an absolute value of interference still obvious, spacing for 1.5 D, isocline tend to independence, air pressure coefficient absolute 1.712, when spacing continue to increase to 3.0 D, two adobe air pressure coefficient isocline around almost completely independent, air pressure coefficient for 1.599, with monomer absolute adobe air pressure coefficient conditions are 1.578 already smaller maximum absolute value.

(2) Center vertical profile of 90 ° wind direction

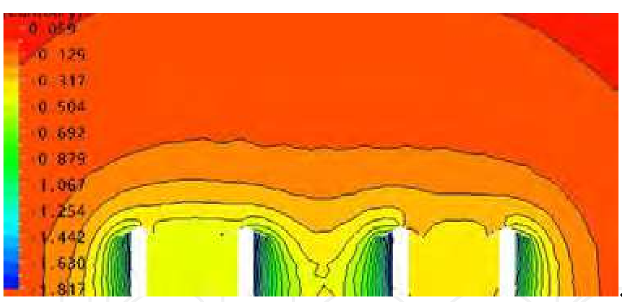
Figure 11 is a different spacing center vertical section, air pressure coefficient isocline can see from figure 11, vertical center section on either side of the air pressure coefficient about isocline obvious symmetry, airflow around side of the surface wind pressure coefficient for exterior wall lateral negative, and the farther from metopic, the small wind pressure coefficient absolute YanXia outside carry with external surface wind pressure coefficient of the measured wind pressure coefficient on the side, almost the same, pick up within the surface wind pressure coefficients were coping negative, but under the surface for the absolute value is opposite bigger. Adobe, adobe has two air around the isocline except in two adjacent area changes remarkably, adobe big changes in other areas. When spacing is 0.15 D, air pressure coefficient isocline surrounded very intense, adjacent area outside carry eaves surface wind pressure coefficient negative, and more monomer when absolute value change, adobe air next pick eaves coefficient is bigger, near the Earth-buildings absolute value change big trend, maximum achieve 2.24, metopic isocline under the changing trends



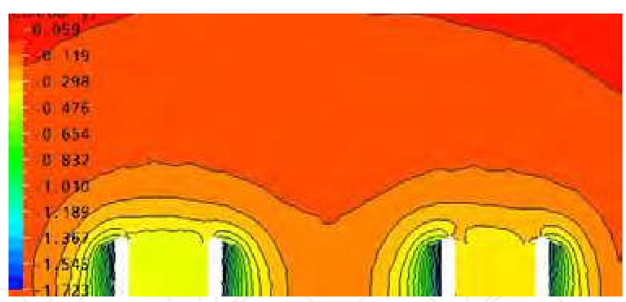
(a) Wind pressure coefficient of center vertical of single building



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

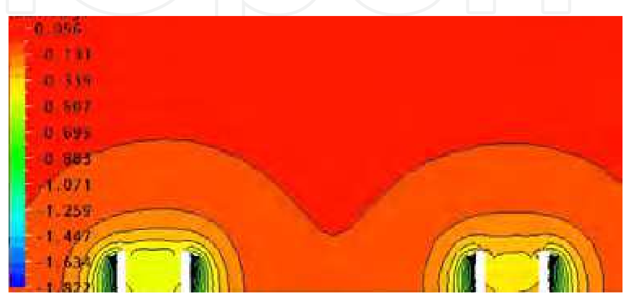


(c) Wind pressure coefficient of center vertical profile when S = 0.75D



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

(e) Wind pressure coefficient of centerprofile when S = 2D



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

Fig. 11. Wind pressure coefficient of 90° wind direction of central vertical profile

and pick eaves is just alike. With adobe spacing 0.75 D increases, spacing, adobe air pressure coefficient between areas surrounded by abate, and absolute phenomenon of wind pressure has reduce and decrease. With increased, when spacing distance, two Earth-buildings center 2.0 D air pressure changes around the isocline section together with monomer Earth-building working outline similar.

3.3 The change rule of average wind pressure coefficient disturbances

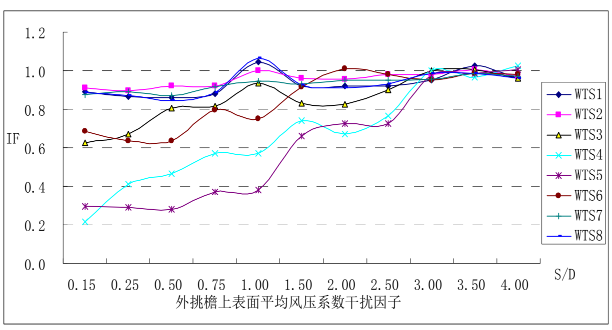
This paper through interference factor to quantitative description of interference effect adobe residences groups:

$$IF = \frac{C_{pI}}{C_{pA}} \tag{2}$$

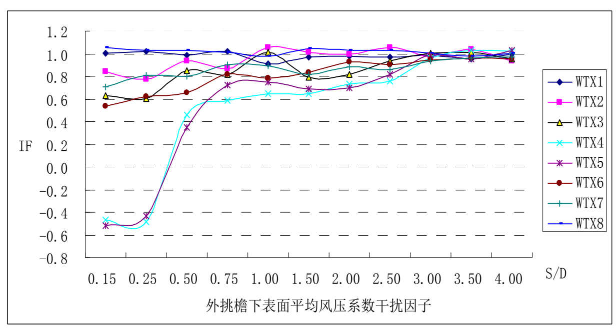
C_{pI} And C_{pA} are separately average wind pressure coefficients after and without wind interference.

3.3.1 0°wind direction

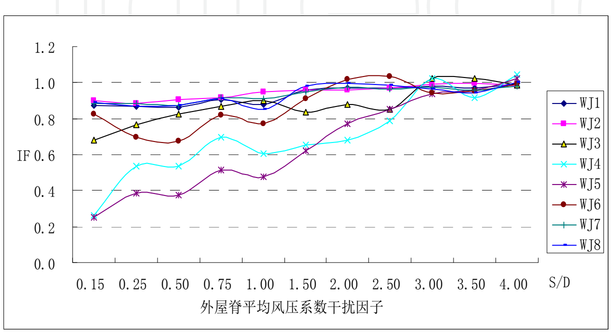
Figure 12 shows that under wind direction 0°, the average wind pressure coefficient interference factors of each zone of the interfered Earth-building roof is changed with the change of distance. In the Figure 12, abscissa S denotes for distance, D denotes for diameter.



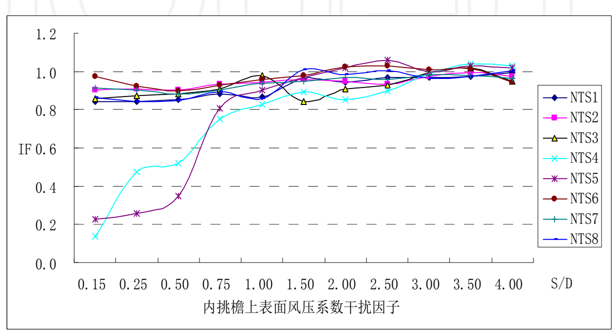
(a) Interference factors of average wind pressure coefficients of on upper surface outside carry eaves



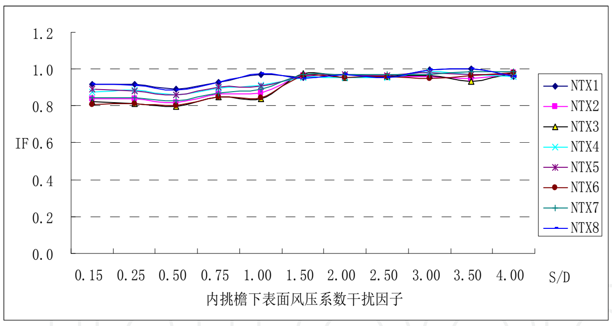
(b) Interference factors of average wind preasure coefficients on under surface of outside carry eaves



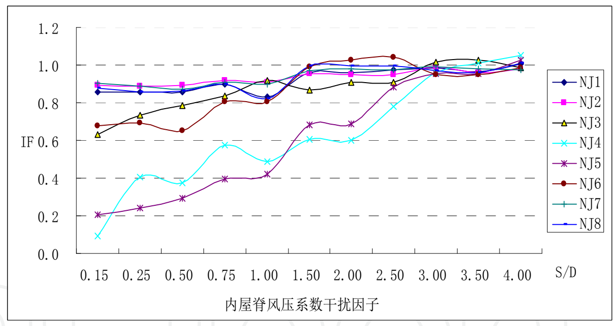
(c) Interference factors of average wind pressure coefficients of on external roof ridge



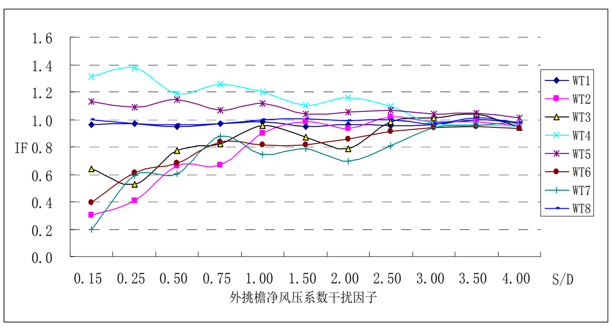
(d) Interference factors of average wind pressure coefficients on upper surface of inside carry eaves



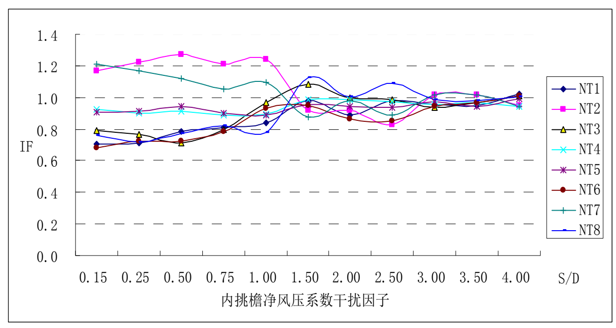
(e) Interference factors of average wind pressure coefficients on under surface of inside carry eaves



(f) Interference factors of average wind pressure coefficients on inner roof ridge



(g) Interference factors of net wind pressure coefficient on outside carry eaves



(h) Interference factors of net wind pressure coefficient on inside carry eaves

Fig. 12. The interference factors of wind pressure coefficient on each roof partition of 0° wind direction

What can be obtained by figure 12:

1. Upper surface of outside carry eaves: to sum up , the wind pressure coefficient in upper surface of outside carry eaves is reduced compared with single Earth-building, along with the increase of distance between, this trend weakened gradually, and when the distance reached 3D, interference factor approached to 1.0, interference affect basically can be ignored. Interference factor WTS1 and WTS8 have minimum amplitude, about10%, the two surfaces are the farthest from the interfered Earth-building. Interference factor WTS4 and WTS5 have maximum amplitude, it reached 70 %, it has great influence with scrambling Earth-building, to the benefit of wind-resistant. Interference factor WTS3 and WTS6 decrease amplitude is about 30%, and interference factor WTS2 and WTS7 change amplitude is less ,is basically similar to WTS1 and WTS8.
2. Under surface of outside carry eaves: Roofing partition is symmetrical, the wind pressure coefficient interference factors under wind direction 0°change have obvious symmetry, and wind pressure coefficient are obviously reduce compared with single Earth-building. Interference factor WTS1 and WTS8 change amplitude is less changed with distance increases, in the 1.0 external floating up and down 5%, surface wind pressure coefficient interference factor WTS2 and WTS7, WTS3 and WTS6 increase with instance increase, among them , interference factor WTS2 and WTS7 are reduce mostly 20%, interference factor WTS3 and WTS6 reduce 40%. It's worth noting that WTX4 and

WTX5 at the leeward side, wind pressure coefficient changing, reducing up to 150%,when the distance increases, the pressure coefficient become negative from positive, interference factor become positive from negative, and when the spacing 3.0D,it is close to 1.0.

3. External roof ridge: The change regulation of the wind pressure coefficient interference factors in external roof ridge is basic same as the wind pressure coefficient interference factors in upper surface of inside carry eaves. The range ability of interference factor WJ1 and WJ8 is minimum, which is about 10%. The range ability of interference factor WJ4 and WJ5 is maximum, which is up to 70%, WJ3 and WJ6 interference factors reduced margin around 30%, WJ2 and WJ7 are same as WJ1 and WJ8 changes.
4. Upper surface of inside carry eaves: From figure 12 (d), in addition to see surface wind pressure coefficient interference factor NTS4 and NTS5 have obvious change, other various surface marked change are small coefficient of wind pressure reduction. Judging from the numerical simulation results, surface wind pressure coefficient NTS4 and NTS5 in smaller values, on change, although magnitude of 0.01 small changes, but the wind pressure coefficient embodied in the disturbances have changed greatly. Overall, wind pressure coefficient interference factor upper surface of inside carry eaves does not change significantly disturbances, the maximum 16%.
5. Under surface of inside carry eaves: from figure 12 (e), the each zoning of the eaves changes consistently, the wind pressure coefficient decreases, it is favorable to stand up the wind. The amplitude of NTX3 and NTX6 is relatively larger,20%，it is the premises where backflow happens inside the Earthen ring. Although it is obstructed by the windward, the wind pressure has decreased; however, airflow returns violently, the wind pressure coefficient of the premises changes more than other premises. When the distance of the Earth-building is 1.5D, the influential factors have approached to 1.0, we can neglect the influences.
6. Inner roof ridge: The wind pressure coefficient disturbances of inner roof ridge and inside carry eaves have the similar variation tendency, but the variation amplitude of inner roof ridge is larger. The variation amplitude of NJ4 and NJ5 are still the biggest, they reach the 80%, the disturbances of NJ3 and NJ6 decrease about 30%, other each surface has the small variation amplitude of about 10%.
7. Bare wind pressure coefficient interference factors in outside carry eaves: For characteristic of Earth-building suction’s 2.5 meter large carry eaves, we consider the up and down surface wind pressure coefficient of carry eaves respectively, then compose them, so we can obtain the bare wind pressure coefficient value that it will be used in design. Increase the interval, the disturbances in previous analysis will increase from the value that less than 1 to 1.0,in considering the bare wind pressure coefficient disturbances, the surfaces disturbances of WT4 and WT5 are both more than 1.0,the reason is that surface wind pressure absorb up and press down, it is disadvantage of structure to withstand wind. With the change of interval, the surface disturbances of WT1 and Wt8 are almost no impact, the reason is that up and down surface offset each other. The surface wind pressure of WT2 and WT7 decrease more than 70%, it is advantageous to withstand wind. The surface wind pressure of WT3 and WT6 also decrease to a certain degree, it is about 40%~50%.
8. Bare wind pressure coefficient interference factors in inside carry eaves: The surface wind pressure coefficient disturbances of NT2 and NT7 increase to a little range, it is about

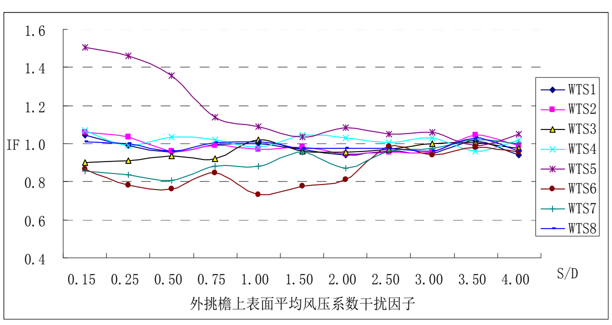
20%.Because of airflow in the Earth-building is backflow, the wind pressure coefficient disturbances of NT1、NT8、NT3、NT6 decrease to a little range, it is about 30%.

Overall, under 0°wind direction, the disturbed is in the upstream, then the disturbing effect is not so obvious, in addition to the individual; each partition of roof is advantageous to withstand wind. If downstream Earth-building have closer distance, the outer cornice of WT4 and WT5 are disadvantage to withstand wind, but value of its surface wind pressure coefficient is less, so it has little influence on withstand wind design. When interval of Earth-building reaches 3D, disturbances will approach to 1.0, the interference effect almost can be ignored.

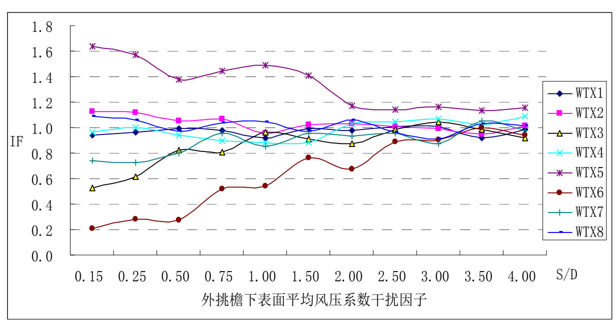
The disturbances of outer roof ridge and outer carry eaves have the similar change rules, the disturbances variation amplitude of inner roof are all smaller than outer roof, and outer carry eaves' absolute value of wind pressure coefficient is bigger than inner carry eaves, in real life situation, destroy the roof mainly begins from lifting tile of outer cornice roof, outer carry eaves is in a very disadvantage condition, so we mainly consider the outer cornice's change rule of wind pressure coefficient disturbances below.

3.3.2 45° wind direction

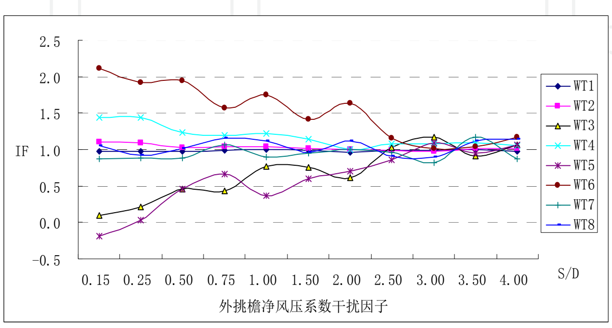
Figure 13 is a 45 ° wind direction under the pressure of the partition coefficient of confounding factors change with the pitch curve.



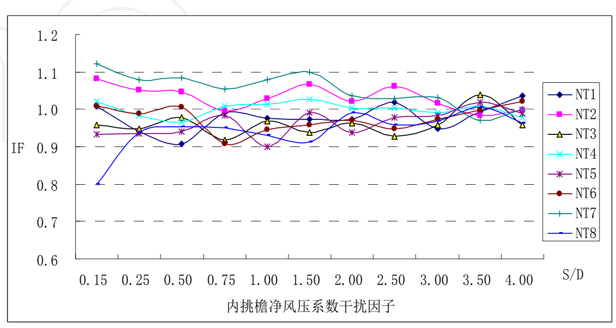
(a) Interference factors of average wind pressure coefficients on the upper surface of outside overhangs.



(b) Interference factors of average wind pressure coefficients on the lower surface of outside overhangs.



(c) Interference factors of net wind pressure coefficients of onside overhangs.



(d) Interference factors of net wind pressure coefficients of inside overhangs.

Fig. 13. The fact interference ors of average wind pressure coefficient on each roof partition of 45^{0} wind direction

What can be drawn from figure 13:

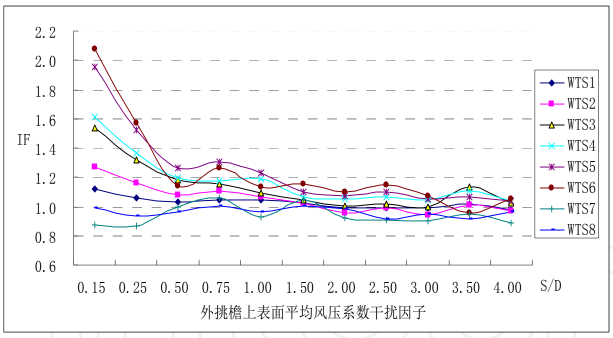
1. External overhangs on the surface: WTS5 in the leeward surface, and adjacent interference Earth-building, where up to 1.5.There are increasing rapidly wind pressure and very adverse wind resistance. WTS6 interference factor is less than 1.0. WTS5 in a relatively inclined all along flow position, and wind pressure coefficient disturbances is asymmetry, because of the other Earth-building influence. There are WTS1, WTS2 WTS4 and WTS8 about 1.0, which interference is not obvious. WTS3, WTS6 and WTS7 interference factor has a small decrease. When the spacing reach to 2.5 D, interference factor affect will be ignore.
2. The lower surface of outer overhangs: WTX5 maximum interference factor of 1.6, WTX3 and WTX7 interference factor of Leeward surface decreases above 30%, Range of other surface pressure coefficients interference factors varies by less, remain in the vicinity of 1.0.
3. The interference factor of net air pressure coefficient of outside carry eaves: it reaches 2.0 or above on WT6, interference effect is serious, but the wind pressure coefficient of this surface is numerical small, 0.1 orders of magnitude, the wind resistant design does not control the surface. The interference factor of WT4 is 1.4 ,which is adverse for wind resistance. The interference factor of WT5 is negative in small spacing, and for WT5 is in the leeward surface where air pressure coefficient is small, the interference effect is beneficial although it is serious. The minimum interference factor of WT3 is 0.1, and it is getting bigger with increases of spacing (the interference factor turns to 1.0 when the spacing is 2.5D). Other interference factors are floating near 1.0; the interference phenomenon is not obvious.
4. The interference factor of net wind pressure coefficient of inside pick eaves: the variation interference factors of each roof partition are small, interference phenomenon is not obvious.

Overall, under the 45 °wind direction, except the interference factors of some roof partitions are near 1.0, the variation of interference factors of WT4, WT5 and WT6 are large, which should be taken into consideration of design.

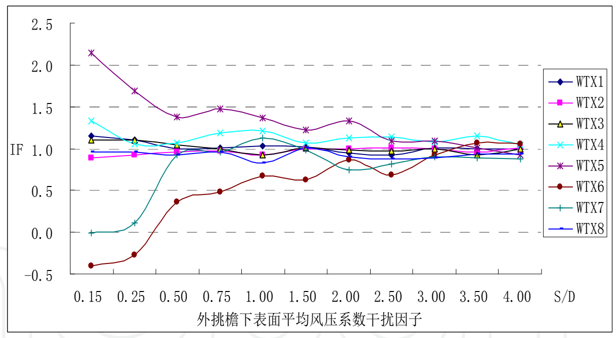
3.3.3 90° wind direction

Figure 14 is a 90° wind direction under the pressure of the partition coefficient of confounding factors is changed with the pitch curve.
What can be drawn from figure 14:

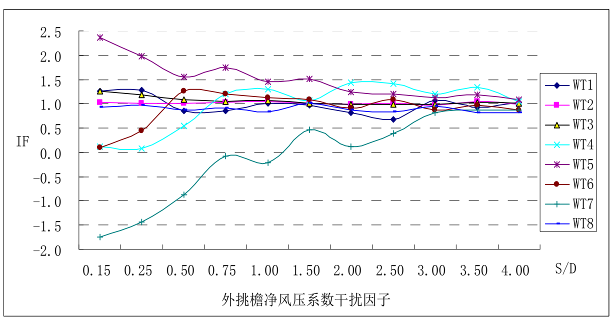
1. External overhangs on the surface: WTS6 interference factor reached a maximum of 2.1, WTS5 interference factor is close to 2.0, WTS4 interference factor 1.6, WTS3 interference factor is also 1.53, with control effect in the gorge, the wind pressure coefficient increases more, is not conducive to Wind. Range of other surface confounding factors varies by less, WTS2 surface disturbance factor of 1.3, WTS7 interference factor of 0.9, WTS1 and WTS8 fluctuations are around 1.0. When the distance increased to 1.5D, external overhangs are reaching the district interference factor of 1.0, as the spacing increases, interference effects gradually weakened.
2. The lower surface of outer overhangs: WTX5 maximum interference factor of 2.1, when wind pressure coefficient of -1.23, air flow around the earth-buildings in the region seriously affected with each other. WTX4 interference factor is also higher, at 1.4. WTX6 and WTX7 interference factor decreases above 100%, large amplitude, but at the leeward wind pressure coefficient values smaller. Range of other surface pressure coefficients interference factors varies by less, remain in the vicinity of 1.0.



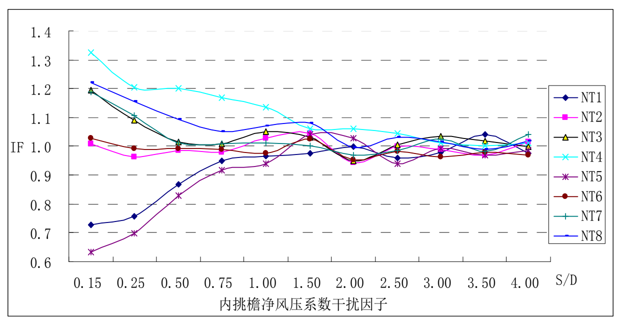
(a) Interference factors of average wind pressure coefficients on the upper surface of outside overhangs



(b) Interference factors of average wind pressure coefficients on the lower surface of outside overhangs



(c) Interference factors of net wind pressure coefficients of outside overhangs.



(d) Interference factors of net wind pressure coefficients of inside overhangs.

Fig. 14. The interference factors of average wind pressure coefficient on each roof partition of 90^0 wind direction

3. Net wind pressure coefficients interference factor outside the overhangs: WT5 surface disturbance factors up to 2.5, the pressure coefficient of 0.53, interference is obvious. WT7 interference factor of -1.7, but the surface is in the leeward wake region, pressure coefficient value is small. WT4 and WT6 interference factor decreases by about 80%, favorable wind. The surface of the other confounding factors the district did not change significantly, at 1.0 fluctuate. When the spacing of 1.5D in the Earth-building. District confounding factors close to 1.0, interference effects can be ignored.
4. Net wind pressure coefficients interference factor in the overhangs: the overhangs at the wind pressure coefficient absolute value of the partition is generally small, between 0.2 and 0.4. NT4 interference factor 1.32, NT5 minimum interference factor of 0.64, Earthen Ring back airflow significantly. NT8 interference factor of 1.22, NT7 interference factor of 1.18, a result of disturbed earth-building wake interference earthen interference facilities was greatly changed.

Overall, in 90 ° wind direction, the interference is obvious, considering the surface pressure coefficients, most of the partition surface disturbance factor greater than 1.0, but considering the superimposed effect of the upper and lower surfaces, the interference is not so prominent, but WT5, NT4 disadvantaged status of wind, earth-building roof to the attention of conservation measures.

4. Conclusion

Through the exhaustive numerical simulation about two typical circular earth-buildings in different wind directions and different spacing, we obtained the distribution characteristics of wind pressure both on the single earth-building and the groups under 0°, 45°, 90°wind direction, the interference effects of wind flow and the change rules that interference factor of average wind pressure coefficient changing with spacing on each roof partition. From the research above we can draw the conclusion that:

1. Numerical simulation can accurately simulate the air flowing field in different wind directions and wind pressure distribution on each roof partition of low buildings. Through the study of wind pressure coefficient and wind velocity contour on two feature faces, we can make qualitative analyses about the wind characteristics in buildings. Under the same wind direction, air flowing field around the earth-building in groups gets close to that of single building along with the increase of building spacing. Under different wind directions, the air flowing field is not the same when building spacing is different.
2. Because of the characteristics of earth-buildings: thick walls, long cornices and tile roof, we mainly analyses the variation of interference factors on each roof partition. The actual situation is that damage of tile roof starts with the lifting of roof tiles from the outside carry eaves. After analysis of the variation of interference factors under different wind directions, we found the change laws of interference factors on the ridge and outside carry eaves are consistent and there is less change of interference factors on the inside roof than the outside. This paper focuses on analyzing the variation of interference factors of wind pressure coefficient on the outside carry eaves under various conditions.
3. Under different wind directions, the variation range of interference factors of average wind pressure coefficient on both the upper and lower surface are smaller than that of net wind pressure coefficient of the outside carry eaves. Interference factors on the upper surface and that on the lower surface mutually reinforce the effects on the windward side and mutually reduce the effects on the leeward side.
4. Compared with a single earth-building, when two earth-buildings are in a line the variation of interference factors is not obvious. When the spacing between two earth-buildings reach 3 times of the bigger radius，the interference factor is close to 1.0 and the interference affect can be ignored basically.
5. when the wind direction is 45° with the line of two earth-buildings，the wind interference is very different to the situation when the wind direction is 0°. When the spacing between two earth-buildings reach 2.5 times of the bigger radius，the interference factor is close to 1.0 and the interference affect can be ignored in the wind resistant design. Under the 45° wind direction, maximum interference factor reach 2.1 on part WT6 which is unfavorable disturbance, but interference factors decrease on part WT5 which is positive.
6. Under the 90° wind direction, most roof partitions are severely disturbed. It shows obvious effect of narrow and wind pressure coefficient increases greatly. The interference factors on part WT5 reach up to 2.5 which are extremely unfavorable to wind resistant and should be paid attention to. When the spacing between two earth-buildings reach 1.5 times of the bigger radius，the interference effect is too weak to be considered in the wind resistant design.

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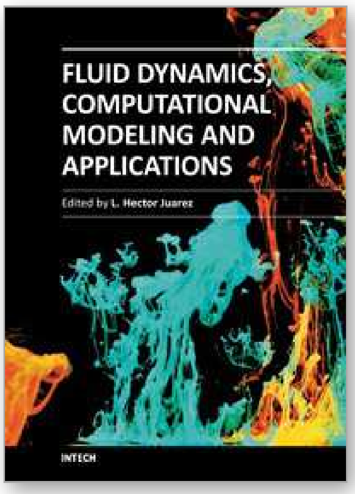

Fluid Dynamics, Computational Modeling and Applications

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The content of this book covers several up-to-date topics in fluid dynamics, computational modeling and its applications, and it is intended to serve as a general reference for scientists, engineers, and graduate students. The book is comprised of 30 chapters divided into 5 parts, which include: winds, building and risk prevention; multiphase flow, structures and gases; heat transfer, combustion and energy; medical and biomechanical applications; and other important themes. This book also provides a comprehensive overview of computational fluid dynamics and applications, without excluding experimental and theoretical aspects.