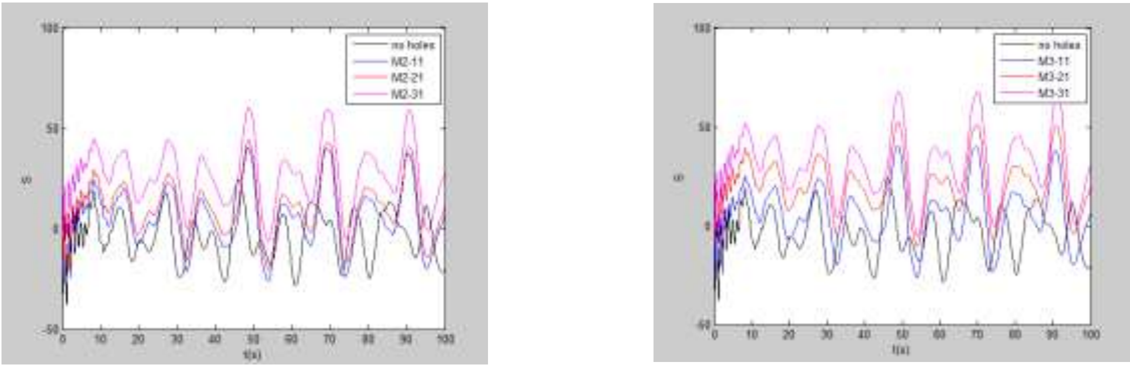
M3-21, M3-31 and no holes results (figure 17), combine with other 8 comparison results chart which are as same as above shown only the number of holes are different while other conditions are same, indicate that the change of holes number has little effect on the compressive stress of the bottom, compared with the bottom compressive stress before opening holes, after opening, the compressive stress of the hole is increased, but the increase in the range of less than 5%, which can be neglected. However as the more number of holes in the process of fluctuating, in the process of fluctuating load, the greater of stress range in change process at the bottom, which is disadvantageous for structure.



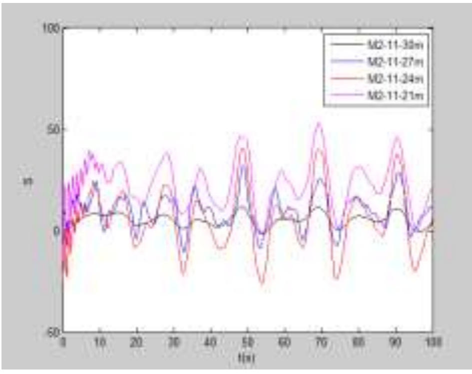
(a) (b)

Figure 18. Comparison results chart of compressive stress of representative nodes in 24 m of each model

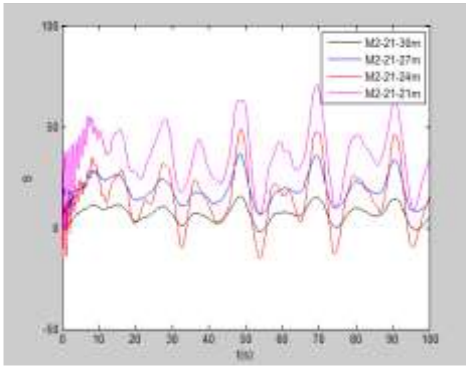
Compare 24 m height node compressive stress of model M2-11, M2-21, M2-31 which only the number of holes is different while other conditions are same (figure 18). At the same height, for the model M2-11, its maximum tensile stress is 0.35 MPa, the model M2-21 whose maximum tensile stress is 0.17 MPa, the model M2-31 whose maximum tensile stress is 0.05 MPa. Combined with the other 8 comparison results chart which only the number of holes are different while other conditions are same, the results show that when the other conditions are the same, as the more the number of holes the greater effect to weak the tensile stress. But for the model M2-31 and M3-31 whose number of holes is 12, in the course of its stress change, the range of stress is significantly higher than other models. This has great damage to the stability of structure.

From model M2-11, M2-21 and M2-31 compressive stress changes chart at different heights (figure 19), for model M2-11, the tension stress is generated at the section near 24 m, the maximum tensile stress is 0.35 MPa; model M2-21 whose maximum tensile stress is 0.17 MPa at the section near 24 m; model M2-31 near 27 m nodes have the maximum tensile stress 0.07 MPa. Combined with other 8 grope graphics which as same as above shows whose only different condition is the number of holes, The results show that as the more holes in the structure, the dangerous cross section will be correspondingly upward shift, and at same level the stress is also reduced.

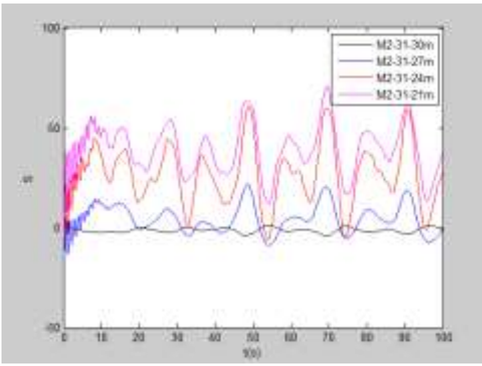
Compare the model M2-11, M2-21, M2-31 and no holes bottom shear stress results (figure 20), combine with other 7 graphics which as same as above shows whose only different condition is the number of holes, it indicates that opening holes can be greatly affected the variation of the shear stress at the bottom, the more holes in the structure the greater shear stress can be weak. From the chart, it also indicate that as the more holes, the smaller the range of the change, which is contribute to the stability of structures under fluctuating loads.



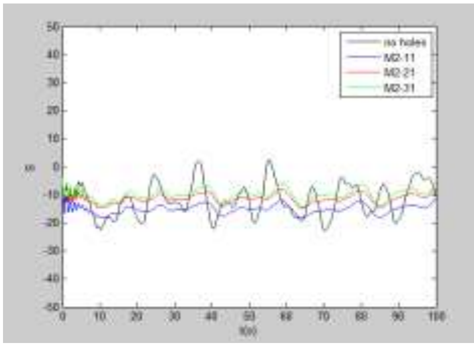
(a)



(b)

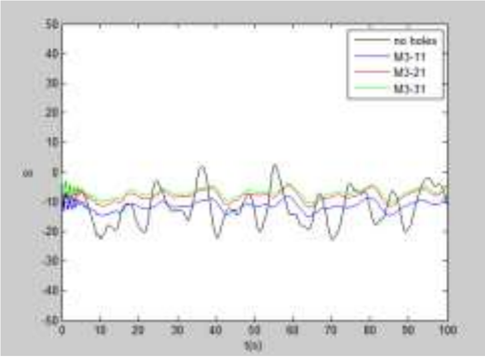


(c)



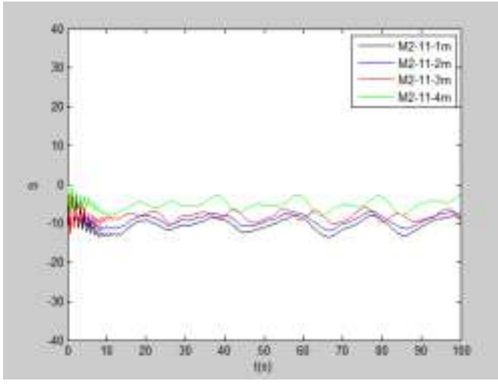
(a)

Figure 19. The change chart of compressive stress of representative nodes of different Model at different height

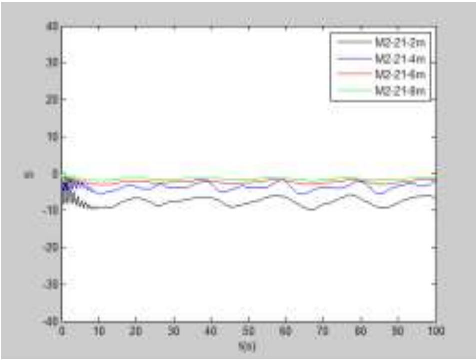


(b)

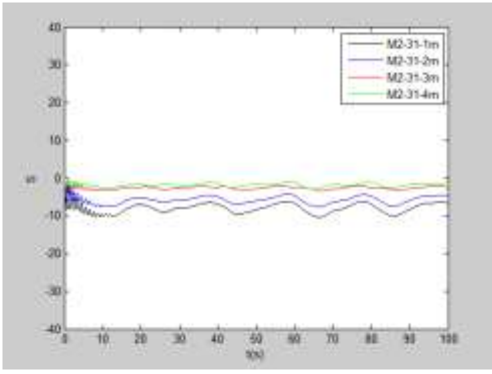
Figure 20. Comparison chart of representative nodes shear stress at the bottom of each model



(a)



(b)



(c)

Figure 21. The change chart of representative nodes shear stress at different height in each model

From model M2-11, M2-21, M2-31, the distribution of the shear stress in different height (figure 21), it can be seen, model M2-11 in the stress variation process, the maximum shear stress of representative node near 3 m height is 0.15 MPa, the probability of excess 0.11 MPa(Design value of shear resistance) in the process is also great, that is near 3 m height it cannot be able to meet the basic requirements of shear resistance; model M2-21 whose node shear stress at 2 m have little probability to excess the design value of shear resistance, basically meet the requirements of shear resistance; the shear stress of model M2-31 have been weaken to the range of Shear resistance within 1 m height. Compare the other 8 groups of the same type graphics, The results show that the change of the number of holes has a great influence on the shear stress, the more holes the faster the shear stress reduction, and the smaller of shear stress at the same height.

V. CONCLUSION

From the above analysis results can be seen, for plate structures, when subjected to fluctuating wind loads, opening holes can be greatly reduced the structural stress, ensure relative stability under strong wind. But the size, location, and number of holes should be analyzed according to the specific circumstances, to select the appropriate open holes states. Based on the investigation of the HongJin tile factory, then established the plate chimney model that have different size, location, and number of holes, after comparing and analyzing the results, found a suitable opening plan for the plate chimney. The wind resistant ability is effectively improved in theory, it provided the theoretical basis for the reinforcement of existing plate type chimney, and also provides a reference in the aspect opening holes of the high confining structure and other plate structures:

Through analysis and discussion there have some relatively general conclusions:

1) When the only different condition is the position, it indicates that the higher of the position of holes the higher of the section that generate tensile stress of the structure, and the smaller of the maximum tensile stress.

2) When the only different condition is the position, the higher the position of the opening holes is, the greater of cutting the shear stress at the bottom, with the height increasing, the higher the hole position The faster of the cutting speed of shear stress, and the smaller the shear stress at the same height.

3) When the only different condition is the size of holes, it indicates that the larger of holes area the higher of the section that generate tensile stress of the structure, at the same height, the stress is relatively smaller, and the maximum tensile stress value of section is smaller. But the larger of holes area, the stress range in change process under fluctuating load is greater; this is extremely unfavorable to the stability of the structure. However when the size of holes is too small its reduction effect for wind load is not obvious. So it needs the appropriate size of the aperture and the appropriate holes area.

4) When the only different condition is the size of holes, it indicates that the larger of holes area the faster the cutting speed of shear stress at the bottom, and the smaller the shear stress at the same height.

5) When the only different condition is the number of holes, the more holes the higher of the section that generate tensile stress of the structure, At the same height, the stress is relatively smaller, and the maximum tensile stress value of section is smaller. But the more holes, the stress range in change process under fluctuating load is greater; this is extremely unfavorable to the stability of the structure, so it needs to choose the appropriate number of holes.

6) When the only different condition is the number of holes, the more holes the faster the cutting speed of shear stress at the bottom, the more holes that is the larger area of holes ,and will be have the faster cutting speed to shear stress, then have the

smaller shear stress at the same height.

7) The compressive stress at the bottom of the structure is increased after opening holes, but the increase is so small which can be ignore. But as the more holes and the larger size of holes, the range of bottom stress change is increasing, this is likely to cause fatigue damage under the action of strong fluctuating wind load, so the number and the size of holes should be reasonably selected to ensure vibration amplitude in reasonable range.

If the choice of reinforcement measure is opening holes, it is recommended the opening number is 8 for plate chimney of HongJin tile factory, double symmetric arranged, hole size in the 90 cm-60 cm, to ensure the change range of structure stress is in a certain value, prevent fatigue damage and reduce the structure's ability to resist strong winds, At the same time, it plays a very good cut of the maximum value; The hole position is best in the middle and upper part, in the case that ensure the structure shear and tensile strength is not weakened, the opening holes can be moved up to the maximum weakening wind load. Of course, it is not satisfied the chimney structure resistance requirement just choose opening holes as the reinforcement measure, other aspects of reinforcement measures, such as the base reinforcement, the stay cable reinforcement, etc., are still to be further study to verify the reliability in the theory and the reality aspect.

ACKNOWLEDGMENT

This work was supported by Shandong Provincial Natural Science Foundation China (ZR2013EEM023), Taishan Scholarship Project of Shandong Province, China (No. tshw20130956), the Project of Shandong Province Higher Educational Science and Technology Program (J14LG06), the Project of Qingdao Construction Technology Program (JK2012-24), the promotive research fund for young and middle-aged scientists of Shandong Province (BS2015HZ017), the Project of Shandong University of Science and Technology Graduate Innovation Fund (YC150330).

REFERENCES

Beste, F. and Cermak (1997), “Correlation of Internal and Area-Averaged External Wind Pressures on Low-Rise Buildings” Journal of Wind Engineering and Industrial Aerodynamics, Vol. **69-71**, 557-566.

Biao F.J. (2010), *Study on Numerical Simulation of Wind-Load on Structures*, Zhejiang University, Hangzhou China. (in Chinese)

Chen Z.Q. (2012), *Bridge Wind Engineering*. Beijing China: China Communications Press. (in Chinese)

Fu J.Y., Zheng Q.X., Wu J.r., Xu A. (2015) “Full-Scale Tests of Wind Effects on a Long Span Roof Structure”, Earthquake Engineering and Engineering Vibration, Vol. **14**(2), 361-372.

Ginger,J.D., Holmes J.D., Kim P.Y. (2010), “Variation of Internal Pressure With Varying Sizes of Dominant Openings and Volumes”, Journal of Structural Engineering, Vol. **136**(10), 1319-1326.

Ginger J.D.,Holmes J.D., Kopp G.A. (2008), “Effect of building volume and opening size on fluctuating internal pressure”, Wind and Structures, Vol. **11**(5), 361-376.

Huang B.C. (2011), *Principle and Application of Structural Wind Resistance Analysis*, Shanghai China: Tongji University Press. (in Chinese)

Li S.K. (2013), “Study of Wind Effects and Equivalent Static Wind Loads on Closing-ground Building with Roof-opening”, Changsha: Hunan University, 183-185. (in Chinese)

Li S.K. and Li S.Y. (2014), “Prediction of Wind Pressure Peak Factor with Non-Gaussian Simulation”, Journal of Vibration and Shock, Vol. **33**(24),123-128. (in Chinese)

Li Z.P. (2010), “Experiment Study and Computational Fluid Dynamics Simulation of Structure with Openings”, College of Civil Engineering of Chongqing University, Chongqing China. (in Chinese)

Li Y.Z. and Yuan M.S. (2008), *Fluid Mechanics*, Beijing China: Higher Education Press. (in Chinese)

Load code for the design of building structures (GB 50009—2012) (2012), Beijing China: China Architecture and Building Press. (in Chinese)

Peng G., Wang X. (2010), “Simulation of Wind Speed Time-Series Using Linear Filter Method and Model Order Identification”, Journal of Guangdong University of Technology, Vol. **27**(2), 32-35. (in Chinese)

Sharma R.N. and Richards P.J. (2005), “Net Pressures on the Roof of a Low-Rise Building with Wall Openings”, Journal of Wind Engineering and Industrial Aerodynamics, Vol. **93**, 267-291.

Sharma R.N. and Richards P.J. (2003), “The Influence of Helmholtz Resonance on Internal Pressure in Low-Rise Building”, Journal of Wind Engineering and Industrial Aerodynamics, Vol. **61**(91), 807-828.

Shen G.H., Luo J.H., Qian T.,Yu S.C., Lou W.J. (2015), “Research on Influence of Length-to-width Ratios on Wind Pressure Distribution of Rectangular-sectioned high-rise buildings”, Building Structure, Vol. **45**(13), 67-73. (in Chinese)

Stathopoulos T. and Luchian H.D. (1989), “Transient Wind Induced Internal Pressures”, Journal of Engineering Mechnics, Division, ASCE, **115**(7):1501-1514.

Xu H.W., Lou W.J., Yu S.C. (2013), “Experiment investigation on influence factors for internal pressure in a building with windward wall opening”, 1st Hong Kong Wind Engineering Society Workshop, City University, Hong Kong, 21-26.

Wang M.R. (2013), *Matlab and Scientific Computing*, Beijing: Electronics Industry Press. (in Chinese)

Yang L., Gurley K.R., Prevatt D.O. (2011), *Probabilistic Modeling of Wind Pressure on Low-rise Building*, Proceedings of 13th International Conference on Wind

Engineering, Amsterdam, Holland: International Wind Engineering Association Press.

Ye J.H., Ding J.H., Liu C.Y. (2012), “Numerical Simulation of Non-Gaussian Wind Load”, Science China Technological Sciences, Vol. **55**(11), 3057-3069.

Yuan B. and Ying H.Q. (2007), “Simulation of Turbulent Wind Velocity Based on Linear Filter Method and MATLAB Program Realization,” Structural Engineers, Vol. **23**(4), 55-61. (in Chinese)

Zhang X.T., Wang Z.D., Wang H.L., Wang L. (2013), “Influence of Wind Effects on Collapsing Process of a Chimney in Blasting”, Journal of Vibration and Shock, Vol. **32**(13), 133-136. (in Chinese)

Zhang Z.H. (2010), *ANSYS 12.0 Application Case Analysis of Structural Analysis Engineering*, Beijing China: Mechanical Industry Press. (in Chinese)

Zhou J., Dou Y.M., Liu X.Y., Sun J.S. (2012), “The test study of shape coefficient of low-rise buildings roof with different positions of openings”, Advanced Materials Research, Vol. **446-449**, 3092-3095.