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Study on Wind Resistant Effect of Plate Type Chimney Based on Numerical Simulation

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As the uncomplicated construction method and low cost, the platy chimney get a wide application in the traditional small tile factory. But because its low wind resistance, it may fall down and hurt people in bed weather. The article for the Hongjin tile factory, one of traditional small tile factory in Shandong of China, and other tile factory had a practical investigation, then use ANSYS software to simulate and ANASYS, use MATLAB software to organize the result data, after analysis and comparison we proposed some advices to enhance platy chimney wind resistance ability. Through the simulation of the wind resistant ability of the slab chimney also provides a reference for strengthening the wind resistant capability of other tall plate structures.

1. Introduction

The tile factory which adopts the traditional production technology is one of labor intensive operation mode factory. As the important production facility, the wet exhaust chimney adopted the structure of plate and tube, used traditional method design and construction, and is widely distributed in Shandong Zibo of China at present. As the uncomplicated construction method and low cost, the platy chimney gets a wide application in the traditional small tile factory. The research of wind resistant effect for plate chimney belongs to the category of structure wind engineering. The research methods of structure wind engineering mainly include: Theoretical analysis, field measurement, wind tunnel test, numerical simulation (He (2012)). Except for continuing the use of traditional research means of wind tunnel test (Peng and Chen (2013)), another new research method - computational wind engineering, become a hot research with the rapid development of computer. When the building walls, windows, doors or other cladding unit under the action of wind load occurred failure (tear, set off) will lead to structural pressure increases suddenly, and the adjacent area of wind pressure distribution is changed, which may lead to produce a progressive collapse of building envelope(Li et al. (2015)).
To sum up, so far, the use of wind pressure on building in practical engineering is still not very ideal, People tend to focus on the external wind load on the structure of the role, the pressure distribution of different holes is not specified in detail. The open hole of the plate structure is rarer in the study of the influence of the wind to the structural pressure. Due to the shortage of the problem research, there is no uniform specification for engineering design. This is also the main reason causing the damage of some building structures under the action of wind load and the continuity damage of other parts of the buildings.

2. Wind speed simulation theory

In this paper, the wind speed is simulated by linear filter method, Linear filtering method also name white noise filtration method, the random process is abstracted to meet certain conditions of white noise, and then through a certain hypothetical system making the proper transformation fitting the time domain of the process. At present, the most common autoregressive model AR(P) (Li et al. (2008)) formula for simulating variable stochastic processes is as follows(Chen (2005)):

$$f(t) = \sum_{k=1}^{p} C(k) f(t - k\Delta t) + B_0 n(t) \tag{1}$$

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Where, $f(t)=[f_1(t),f_2(t),f_3(t),\cdots f_n(t)]T$, $C(k)$ is the $p\times p$ order autoregressive coefficient matrix, Δt is the time interval, p is auto regressive coefficient, $n(t)$ is Zero mean variance of 1 of the standard white noise, B_0 is its coefficient matrix.
In the formula (1) both sides multiply by $f\ (t\text{-}j\ \Delta t)$ and take the mathematical expectation, obtain the following equation:

$$R_{ff}(j\Delta t)=\sum_{k=1}^{p}R_{ff}[(j-k)\Delta t]C^{T}(k) \quad j=1,2,3,\cdots p \tag{2}$$

$$R_{ff}(0)=\sum_{k=1}^{p}C(k)R_{ff}(k\Delta t)+B_0R_{nf}(0) \tag{3}$$

In formula (2) both sides multiply by $n(t)$ and take mathematical expectations, get $R_{fn}(0)=B_0$. Make $R_{nf}(0)=R_{fn}^{T}(0)=B_0^{T}$ into formula (3), get:

$$R_{ff}(0)=\sum_{k=1}^{p}C(k)R_{ff}(k\Delta t)+B_0B_0^{T} \tag{4}$$

Making fourier transform for the target self (mutual) spectral density function can obtain self (mutual) correlation function. When the correlation function is brought in formula (1) we can solution $C(k)$（k=1,2,3⋯, p）. Once $C(k)$ is known, it can be solved by formula (4) of the triangular matrix B_0. The random fluctuating wind speed can be generated when all these coefficients matrix are take into formula (1) and make recursive calculation (Li and Zhang (2014)).

3. The wet exhaust chimney of Hongjin tile factory

The Hongjin tile factory is located in Zibo Shandong of China, it built in Hilly Areas. Production workers of the tile factory mostly are migrant workers, who had low security awareness and low safety skills. The tile factory which adopts the traditional production technology is one of labor intensive operation mode factory. As the important production facility, the wet exhaust chimney adopted the structure of plate and tube, used traditional method design and construction (Zhang et al. (2013)).
Table 1. Lie the wet exhaust chimney parameters, Figure 1., figure 2. display space layout of wet exhaust chimney.

Table 1: The wet exhaust chimney parameters of Hongjin tile factory

project	Size
Upper width	105cm
Lower width	270cm
length	1830cm
Height	3200cm
Structure	Material: clay brick, Concrete mortar caulking; The following 20m high chimney wall thickness is about 25cm, 20m above wall thickness about 12cm Shape: Top thin bottom thick; Ladder structure.

4. Numerical simulation

4.1 Mechanics model establishment

Before opening holes the model height is 32m, the upper and lower widths are consistent with 1830cm. The chimney model is built and the meshing is shown in Figure 3.

After opening hole the chimney model height unchanged for the 32m, under the same length as 1830cm, the number and position of the opening holes are shown in Table 2. The chimney model is built and the meshing is shown in Figure 4.

Figure 1: Hongjin tile factory plate wet exhaust chimney map (east-west)

Figure 2: The layout of Hongjin tile factory chimney (north-south)

Table 2: The design parameters of plate chimney opening holes

Opening hole position	Number of holes	Opening hole specification
18 m height, average distribution along the strike	2	Diameter 80cm round hole
21 m height, average distribution along the trend	2	Diameter 80cm round hole
24 m height, average distribution along the trend	2	Diameter 80cm round hole
27 m height, average distribution along the trend	2	Diameter 80cm round hole
note	The pore size of chimney meets the requirements of structural strength and the convenient construction; The ventilation hole is rolled steel welded construction, convenient for construction.	

Figure 3: Plate type multi tube wet exhaust chimney mechanical model (before opening holes)

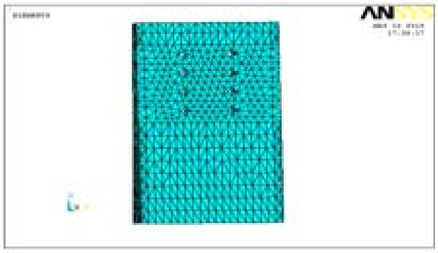


Figure 4: Plate type multi tube wet exhaust chimney mechanical model (after opening holes)

4.2 Load simulation

The loads are mainly vertical wind loads, which are non-uniform variation along the height, we use MATLAB software to program linear filtering method (Shu et al. (2002)), and from calculation we get simulated wind speed change chart at different height (Li and Du (2008). The main parameters of the simulation are shown in Table 3.

Table 3: The main parameters of the simulation

parameter	Value	parameter	Value	parameter	Value
Total height (m)	32	Simulate spacing (m)	2	Computational order	4
Ground roughness	0.003	Initial frequency (HZ)	0.01	Initial time	0.1
Average wind speed at 10m (m/s)	20.515	Cutoff frequency (HZ)	10	Total time points	2048
Simulate points	15	Frequency increment (HZ)	0.01	Time increment (s)	0.1

Davenport spectra are used in the simulation, the time variation of the wind speed of each point is calculated by MATLAB programming which are based on the existing formula. Figure 5 and Figure 6 are respectively the 18m and 29m height simulated point fluctuating wind speed chart.
We change the wind speed with Bernoulli equation into the wind pressure variation with time (Zhang (2006)). Figure 7, Figure 8, are respectively the 18m, 29m height pressure time history chart.

$$P = \frac{1}{2}\rho V^2 \qquad (5)$$

Where, P is pressure; ρ is air density; V is fluctuating wind speed.

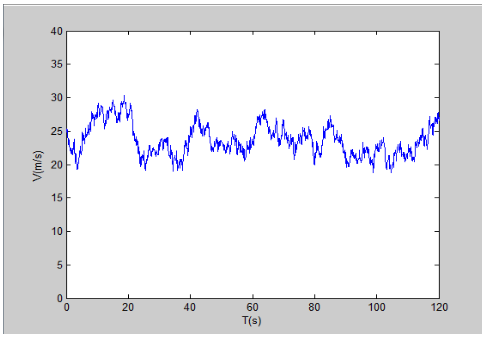


Figure 5: Wind speed time history chart of 18m height simulation point

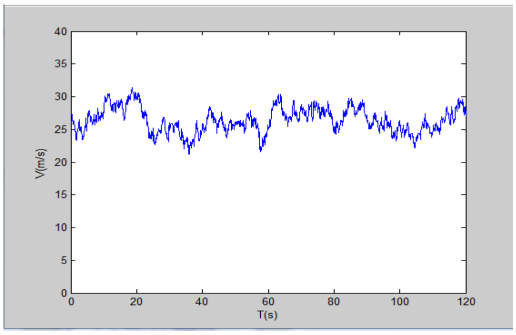


Figure 6: Wind speed time history chart of 29m height simulation point

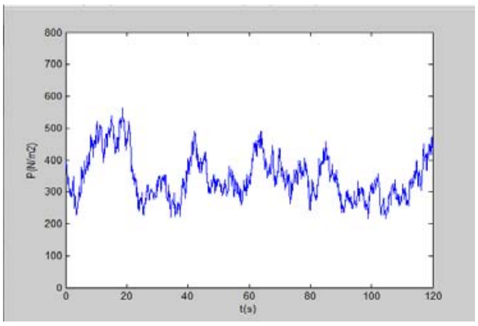


Figure 7: Wind pressure time history chart of 18m height simulation point

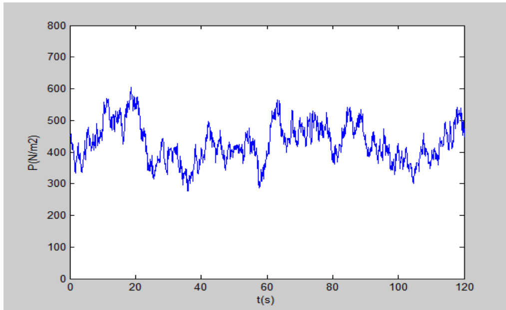
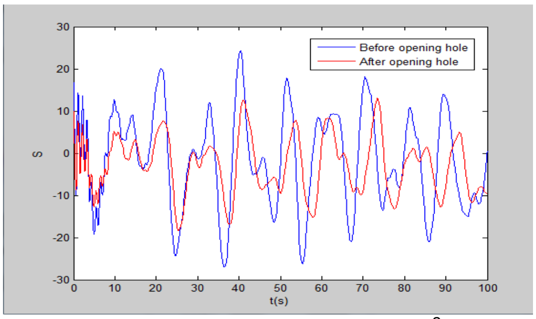


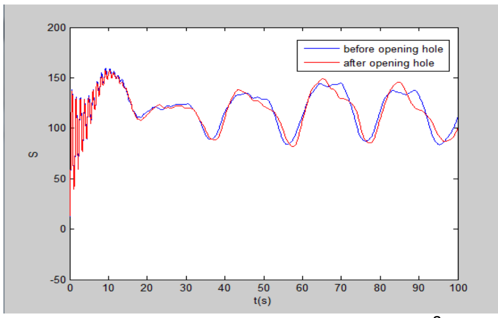
Figure 8: Wind pressure time history chart of 29m height simulation point

Then the wind pressure varied value at each height is imported into the ANSYS software, a fluctuating pressure load is applied to the model. When the calculation is finished, achieve 30 simulation nodes' ,which are located in different height, the shear stress and the compressive stress history change values, make time history chart with MATLAB software (Yuan et al. (2007)), Finally make overall process analysis.

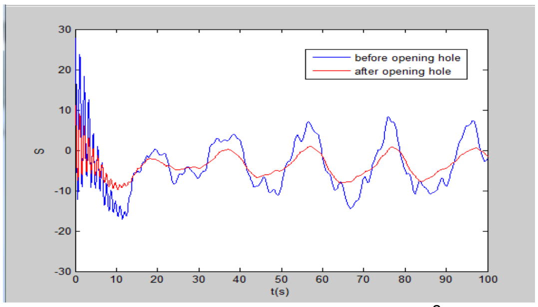
5. Result analysis



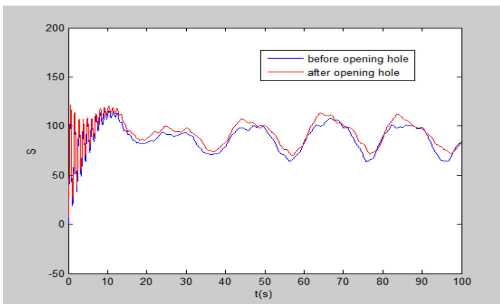
(1) *simulation node at 0m height* （*N/cm*^{2}）



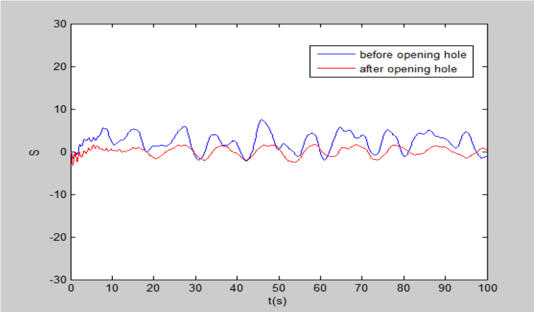
(1) *simulation node at 0m height* （*N/cm*^{2}）



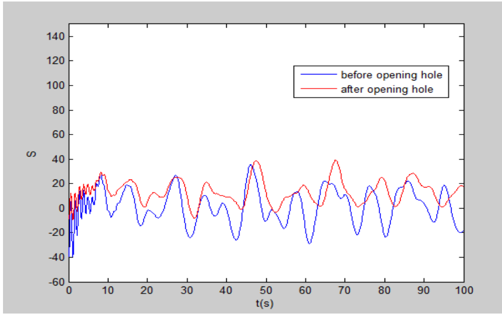
(2) *simulation node at 8m height* （*N/cm*^{2}）



(2) *simulation node at 8m height* （*N/cm*^{2}）



(3) *simulation node at 25m height* （*N/cm²*）



(3) *simulation node at 25m height* （*N/cm²*）

Figure 9: Shear stress time history chart

Figure 10: Compressive stress time history chart

Figure 9 and Figure 10 are respectively the shear stress and the pressure stress time history chart of the partial nodes obtained under the effect of fluctuating loads.
Combined with other results chart analysis:
The shear stress at the substrate before and after opening holes all exceed shear stress intensity design value 0.11Mpa (Ministry of Construction of the People's Republic of China(2012)), all did not meet the requirements. The shear stress around 8m before opening holes reached 0.25Mpa, and frequently exceed shear strength design value, but after opening holes the maximum shear force is 0.105Mpa, Shear force decreases rapidly, meet the requirements.
The maximum compressive stress value at the substrate before and after opening holes respectively reached 1.61Mpa and 1.63Mpa, all exceed compressive stress intensity design value 1.50Mpa. At the height of 25m, the maximum tensile stress reached 0.39Mpa, and frequently exceeds 0.23Mpa, the masonry tensile strength design value. But the maximum tensile stress after opening holes is 0.11Mpa, fully meet the requirements.
From the results of graphics can be seen, whether it is tensile or shear stress after opening holes, compared with no holes, the magnitude and the mode of the stress change have been changed, The stress magnitude is reduced after opening holes, changing mode tend to smooth, This indicates that for plate structures opening holes has a great influence on the stability of the structure, can improve the fatigue stability of structure. For plate structures under fluctuating wind loads, Suitable opening contributes to improve its resist ability, but under different open hole parameters, It has yet to be further studied its influence size for the structure resistance and the distribution situation of wind pressure on the plate structure.

6. Conclusions and suggestions

Because of the main focus of the research on the structure opening is on the semi enclosed and closed buildings or structures, study the opening hole on the wind-induced internal pressure and the influence of pressure distribution around, little is involved the simple plate structure or the tall confining structure. This paper based on the investigation into the Hongjin tile factory, and use ANSYS software to build model, simulation and calculation, Comparative and analysis the different influence of the opening plate - shaped structure, under the impact of the wind load on the structure. The results show that the measure of opening the hole at the right position of the chimney can effectively reduce the stress swing range of masonry structure, reduce the stress intensity of dangerous section, enhance fatigue stability of reinforced structure, reduce the stress intensity of the dangerous section, and reduce the structural stress at the same height, And with height increase, stress decreased faster than no holes plate-structure. Make sure the masonry structure keep stable under the action of strong fluctuating wind pressure, and ensure no structural damage occurred. For the chimney structure, to prevent itself resistance is not reduced due to the opening holes the following measures can be used as an auxiliary reinforcement:
1) Strengthening treatment in the substrate
Because the shear stress and the compressive stress all cannot meet the requirements before or after opening holes, so we advise reinforce the substrate within the range of 0.25m of masonry structure. We can adopt concrete pouring slope to improve masonry shear and compressive resistance bearing capacity.
2) High chimney cut processing
Based on the investigation and research of 8 same type of plate with multi tube type wet chimney distributed in the same area, to ensure the premise of meeting the dehumidifying and ventilation ability of chimney, the chimney height is 27m, part of higher can be cut height processing by professional construction team. As the chimney of Hongjin tile factory height is 32m, so you can then cut the high processing.
3) The chimney exhaust hole and reinforcement design

The flexible steel cables erect between 16m and 22m of the plate multi tube wet exhaust chimney, and fastened on the ground in the chimney, symmetric set 11 sets on each side, The upper end of cable fixed ventilation design holes, and take the anchor fixed, To avoid because the pressure imbalance , then bring to chimney sustained destructive vibration.
Through the simulation of the wind resistant ability of the slab chimney, in addition to provide suggestions for strengthen the construction of wind resistant ability to the actual existence project, It also provides a reference for strengthening the wind resistant capability of other tall structures. However, because of the impact of the open hole on the structure, and the research on the reinforcement measures are very few, theory is not perfect, in this paper, numerical model is made just for a preliminary comparative analysis, And then put forward the corresponding measures, for the different pressure distribution and vibration condition caused by different holes parameters and other reinforcement conditions, still need to be further studied.

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