Study on Parameters of Quake-Proof for Shen-Wu Gate in the Forbidden City in China

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ABSTRACT :

Chinese ancient buildings are mainly made of wood.For thousands of years they have experienced sorts of earthquakes but remain intact.Their characters of quake-proof are related closely to their constitution.In order to study influences of constitutions such as Tou-Kung,Tenon-Mortise joints,Cejiao ,base conditions and so on , the Shen-Wu Gate in the Forbidden City is taken as an example.Its finite element model is built ,Elcentro waves in 3 directions are imposed on the model for dynamical analysis.Results show that the constitutions above are all helpful for seismic resistance.The aseismic characters of Shen-Wu Gate are worth studying for modern people.

KEYWORDS: Wooden structure,parameters for quake-proof,dynamical analysis,aseismic constitution,Shen-Wu Gate in the Forbidden City in China

Chinese ancient buildings are mainly made of wood,for thousands of years they have experienced sorts of earthquakes but remain in good conditions.The character of quake-proof of Chinese ancient buildings are related to their constitutions:Tenon-Mortise joints of beams and columns can reduce vibration by extruding between tenon and mortise;Layered Tou-Kungs are just like springs which can isolate vibrations;the Cejiao constitution enhances the stability of structure;The root of column is not inserted into the stone base but superimposed above the stone base,which produces energy dissipation by friction.In order to study the effects of constitutions of Chinese ancient buildings to their aseismic character,the Shen-Wu Gate in the Forbidden City is taken as an example to be analysed whose finite element model is shown in Figure 1.

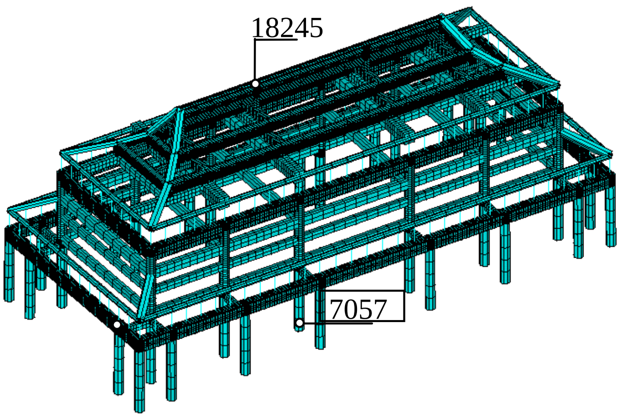


Figure 1 Finite element model of Shen-Wu Gate

1.PARAMETERS CONFIRMATION

In order to study how Tou-Kung,Tenon-Mortise joints,Cejiao and base conditions affect the building's aseismic character,5 work conditions are listed in Table 1 which will be discussed in the following.

Table 1 Work conditions

Condition Numbering	Stiffness for Tou-Kung	Stiffness for Tenon-Mortise	Base constraint	Consider Cejiao
1	K_1	K_2	Swivel	Yes
2	0	K_2	Swivel	Yes
3	K_1	∞	Swivel	Yes
4	K_1	K_2	Swivel	No
5	K_1	K_2	Semi-rigid	Yes

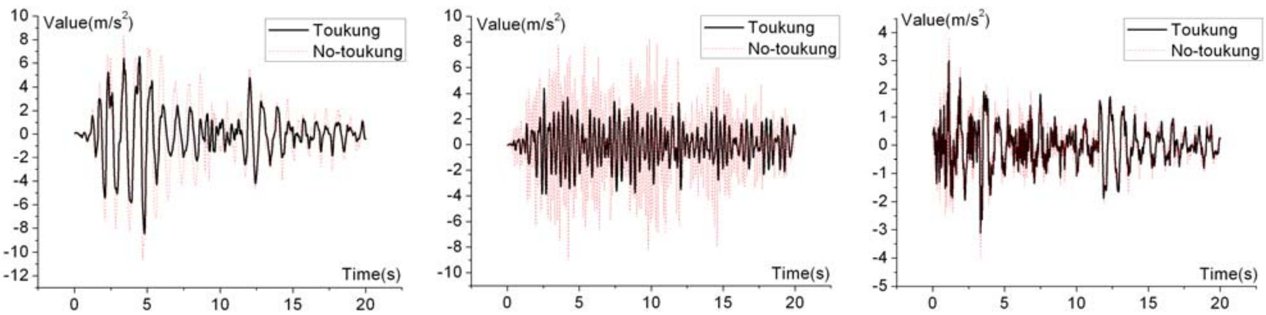
When studying the effects of Tou-Kung,condition 2 can be contrasted to condition 1;When studying the effects of Tenon-Mortise joints, condition 3 can be contrasted to condition 1;When studying the effects of Cejiao, condition 4 can be contrasted to condition 1;When studying the effects of base condition, condition 5 can be contrasted to condition 1.

According to obtained achievements(Zhang,2003;Sui,2006), stiffness values for Tou-Kung(K_1) are: $K_x = K_z = 0.3\times10^6 N/m$， $K_y = 5.5\times10^6 N/m$， $K_{\theta x} = K_{\theta y} = K_{\theta z} = 0$;Stiffness values for Tenon-Mortise joints (K_2) are: $K_x = K_z = 1.69\times10^6 N/m$， $K_y = 0$， $K_{\theta x} = K_{\theta y} = K_{\theta z} = 1.5\times10^5 N/m^2$ .Where x and z represents horizontal directions,z represents vertical direction. Elcentro waves in 3 directions are imposed on the structure.For each direction the peak acceleration value is 400g, time duration is 0.02 second and the total loading time is 20 seconds.During analysis node 18245 which is on roof position is selected whose response curves of acceleration in x,y and z directions will be studied.

2.PARAMETERS ANALYSIS

2.1.Tou-Kung

In order to study the effects of Tou-Kung,acceleration response curves of condition 2 are contrasted to those of condition 1,which are shown in Figure 2.It is clear that the peak acceleration values of the structure considering Tou-Kung are lower than those of without Tou-Kung,while in vertical direction(y direction) the decrease of peak value becomes more obvious,which indicates that Tou-Kung isolates mainly in vertical direction.

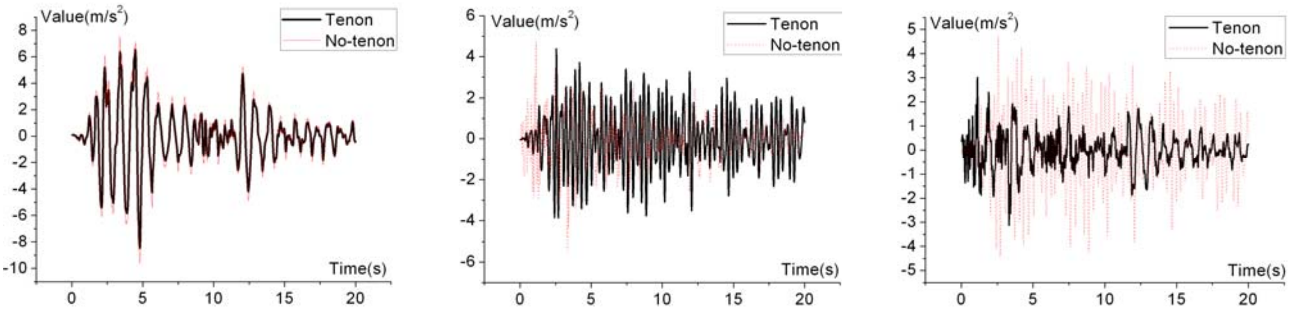


(a) Ax18245 (b)Ay18245 (c)Az18245

Figure 2 Acceleration response curves of node 18245 for Tou-Kung condition

2.2. Tenon-Mortise Joints

In order to study the effects of Tenon-Mortise joints, acceleration response curves of condition 3 are contrasted to those of condition 1,which are shown in Figure 3.It is clear that when considering the connection joint of beam and column as tenon-mortise joint (semi-rigid joint),peak values of acceleration in x,y and z directions are lower than those considering the joint as a rigid joint.Thus the Tenon-Mortise joint is just like a damper which can reduce response of earthquake by friction and extrusion.

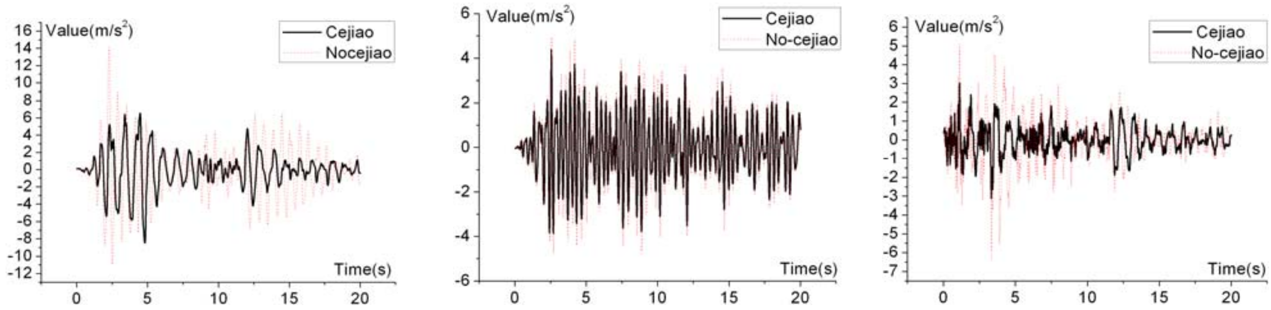


(a) Ax18245 (b)Ay18245 (c)Az18245

Figure 3 Acceleration response curves of node 18245 for Tenon-Mortise joints condition

2.3 .Cejiao

In order to study the effects of Cejiao, acceleration response curves of condition 4 are contrasted to those of condition 1,which are shown in Figure 4.It is obtained that by Cejiao the peak values of acceleration curves have decreased in x,y and z directions,which shows the character of aseismic of Cejiao.On the other hand,when considering Cejiao,curve of axial force of element 7057 is $2.97\text{x}10^5$N,which is about 20% more than that of without Cejiao.Thus by Cejiao the structure not only reduces response of earthquake but also makes more full use of compression strength of the column to increase the frictional force between column root and base.



(a) Ax18245 (b)Ay18245 (c)Az18245

Figure 4 Acceleration response curves of node 18245 for Cejiao condition

2.4.Base Condition

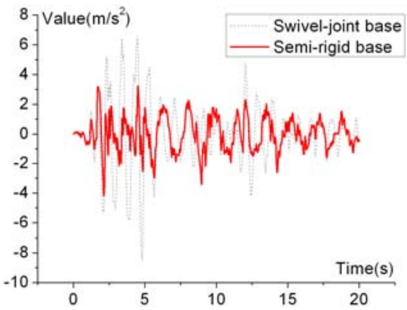
The column roots of many ancient buildings are not inserted into the stone bases,but superimposed above the stone bases,one of which is shown in Figure 5.The superimposed base can be simulated by a horizontal frictional damper,whose equivalent viscous damping coefficient is(Zhou,2006): $c_d = 4P_y d_0 T/\left(2\pi^2 d_0^{\,2}\right)$.

Where, P_y represents frictional force, $P_y = \mu G/4$; d_0 represents maximum sliding displacement of the damper, here $d_0 = 0.13m$; T represents natural period of the structure.

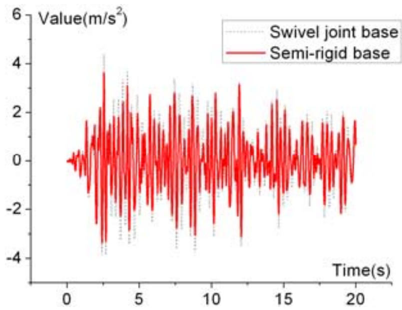
(a) Without column

(b)With column

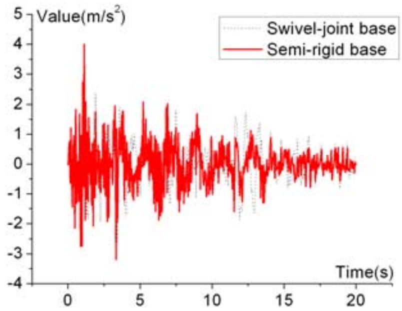
Figure 5 Stone base



(a) Ax18245



(b)Ay18245



(c)Az18245

Figure 6 Acceleration response curves of node 18245 for base condition

In order to study the effects of base condition, acceleration response curves of condition 5 are contrasted to condition 1,which are shown in figure 6.It is obvious that when considering the column roots superimposed above the stone base(semi-rigid connection mode),peak values of acceleration in x,y and z directions have become lower than those of swivel base conditions,which indicates vibration absorption by friction between column root and stone faces.

Acceleration values for all conditions above are shown in Table 2.

Table 2 Acceleration values for different conditions(m/s^2)

Condition	Ax	Ay	Az
1	8.47	4.38	3.11
2	10.63	8.94	4.04
3	9.60	5.44	4.73
4	14.16	4.95	6.41
5	4.18	3.62	2.88

3.CONCLUSION

Results all above indicate that constitutions such as Tou-Kung,Tenon-Mortise joints,Cejiao and superimposed base condition and so on are all helpful for seismic resistance,which reflects experiences obtained by Chinese ancient people during the process of fighting against natural disasters.These techniques are still worth studying for modern people.

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