

Principle of 0.2V₀ in frame-tube structures under expected rare earthquake

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Abstract. Shear walls could present much more lateral stiffness than frames in frame-tube structures, so the load carried by frames may increased because of the redistribution of plastic internal force induced by the damage of walls under expected rare earthquakes. To ensure structures with double fortification lines for earthquake, columns should be designed with plenty of lateral stiffness as the principle of 0.2V₀ specified by national code. Numerical results show that only with enhancement of load bearing capacity by amplifying the reinforcement of frame sections, those structures without enough frame stiffness may exhibit weaker dynamic performance than we expected.

Introduction

For frame-tube structures without vertical abrupt change, shear force carried by frames should not less than 20% of the total base shear force[1], which is proposed by the national code for concrete structures of tall building[1] as follows:

$$V_f \geq 0.2V_0 \quad (1)$$

where

V₀ is the base shear force carried by whole structure;

V_f is the shear force carried by frames of each floor.

As the stiffness of core walls was designed to be much more dominant than outer frame tube in frame-tube structures, this would make the shear walls being damaged as the first fortification line in expected rare earthquake, with the redistribution of plastic internal force, frames would contribute more lateral stiffness and then carry more seismic force than in frequent earthquake. According the concept of multi earthquake fortification lines, the frames should be designed with enough stiffness to carry the shear force as shown in Eq.1 to be qualified as the second line of earthquake fortification.

Although the stiffness deficiency of columns can be modified automatically by professional software[2] during the process of design by amplifying rebar of sections to improve the load bearing capacity and ductility of frame sections, but this wouldn't improve the lateral the stiffness significantly, and the structure may even exhibit quite different nonlinear properties as we expected. Engineers has researched about this problem[3,4], and elastic-plastic analysis of some engineering also has been taken into account[5,6].

By numerical methods, the principle of 0.2V₀ for frame-tube structures was researched in this paper by using ABAQUS. The sections of columns were adjusted finely without significant change of structural performance under frequent earthquakes, and then nonlinear time-histories of structural damage for different models were researched to reveal the importance of 0.2V₀ principle in expected rare earthquakes.

Static analysis

A frame-tube structure with shear wall tube inside and concrete frames outside is shown in Fig.1. The 32-floor structure was designed with fortification intensity 8.

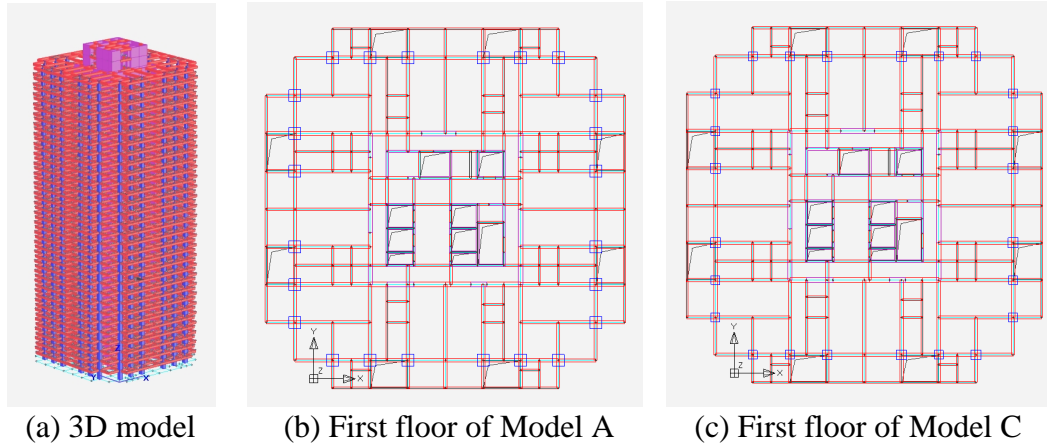


Fig.1 Frame-tube structure

To find the relationship between shear force carried by columns and the structural performance under expected rare earthquakes, some of the column sections were adjusted to change the stiffness contribution of frames without any violation of relevant national codes. The standard floor of model A and model C are shown in Fig.1.

Results of mass and natural periods are listed in Tab.1 and it means that these section adjustments have little influence on the structural periods.

Tab.1 Mass and natural periods

Model	Mass(Ton)	T1(s)	T2(s)	T3(s)
Model A	44106.453	2.465	2.359	2.317
Model B	43576.781	2.486	2.382	2.333
Model C	43272.258	2.503	2.399	2.345

The contribution of outside columns are listed in Tab.2 for both base shear force and overturning moment proposed by response spectrum method under frequent earthquakes.

Tab.2 Base shear force and overturning moment of response spectrum

Model	V_Col(kN)	V_Tot(kN)	V_Ratio	M_Col(kN.m)	M_Tot(kN.m)	M_Ratio
Model A(026)	3643.5	14114	25.81%	215793.3	823145.4	26.2%
Model B(020)	2853.0	13944	20.46%	204269.5	816487.4	25.0%
Model C(015)	2270.4	13847	15.40%	196845.7	812804.8	24.2%

As the results shown in Tab.2, the difference of shear force induced by column section adjustment is much more evident than overturning moment. According to the national code, the shear force of model C (015) should be amplified to $0.2V_0$ to amplify the reinforcement, so the frames could be qualified for the second fortification line of earthquake.

Constitutive relationship and seismic wave

The constitutive relationship of damaged plasticity is used for concrete[7,8] and the damp ratio is assumed as 0.05, rebar is assumed as kinematic hardening with damp ratio equal to 0.02. The concrete uniaxial skeleton curve of compression and the damage can be formulated with Eq.2 and Eq.3 respectively:

$$s = (1 - d_c) E_c e \quad (2)$$

$$d_c = \begin{cases} 1 - \frac{r_c n}{n - 1 + x^n} & x \leq 1 \\ 1 - \frac{r_c}{a_c (x - 1)^2 + x} & x > 1 \end{cases} \quad (3)$$

The structure was loaded with the seismic wave shown in Fig.2 and the time-history lasted for 20s .

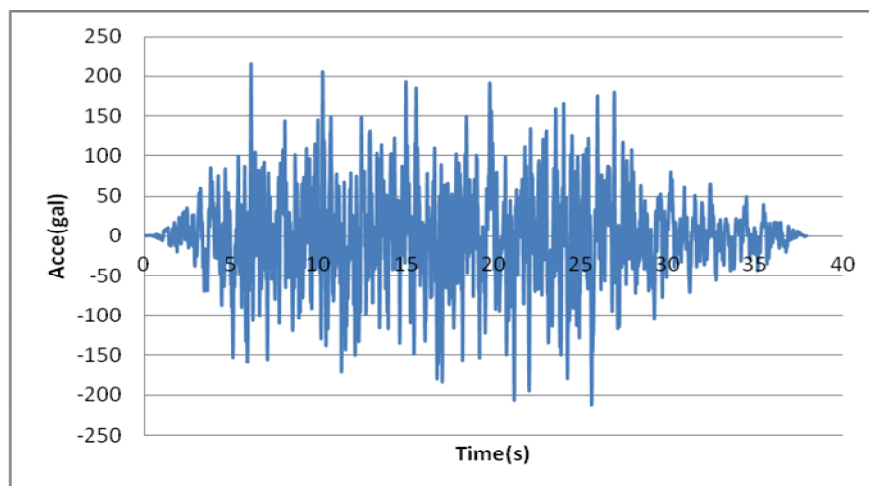


Fig.2 Seismic wave

The failure criteria of reinforced concrete members are assumed with both compression damage of concrete and plastic strain of rebar. For each section of both frames and shear walls, if the average value of concrete compression damage exceeds 0.3 or the steel plastic strain exceeds 0.012, it would be regarded as being damaged seriously.

Time-history of elasto-plasticity

1. Failure of members

The time-history of statistics for those members damaged seriously is shown in Fig.3. It can be seen that shear walls were damaged earlier than frames in each model. After shear walls being damaged, redistribution of plastic internal force would lead to damage of frame beams, and at last, frame columns were damaged. This progress of damage is just the concept of multi fortification lines for earthquakes

But there is still significant difference among these three models. It is obvious that both beams and columns of model C were damaged earlier and more seriously than the other two models. The reason is that the lateral stiffness of model C is too weak to carry the additional loading transferred from those damaged shear walls. Plenty of stiffness of frames can delay the damage of the whole structure with its second fortification line for earthquake.

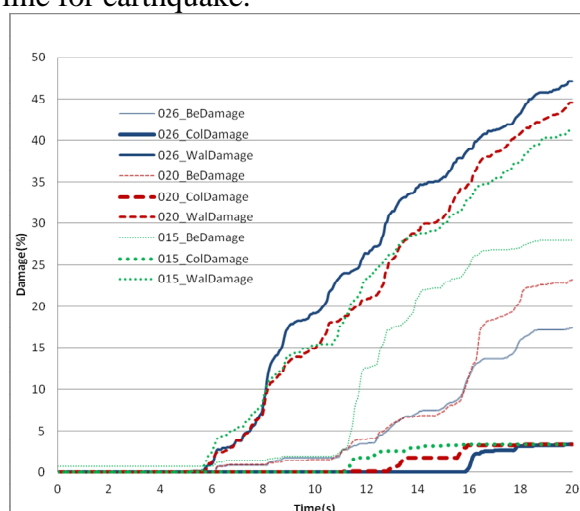


Fig.3 statistic time-history of concrete compression damage

2. Displacement angle

Envelops of both elastic displacement angle proposed by spectrum method and elastic-plastic displacement angle proposed by time-history are shown in Fig.4.

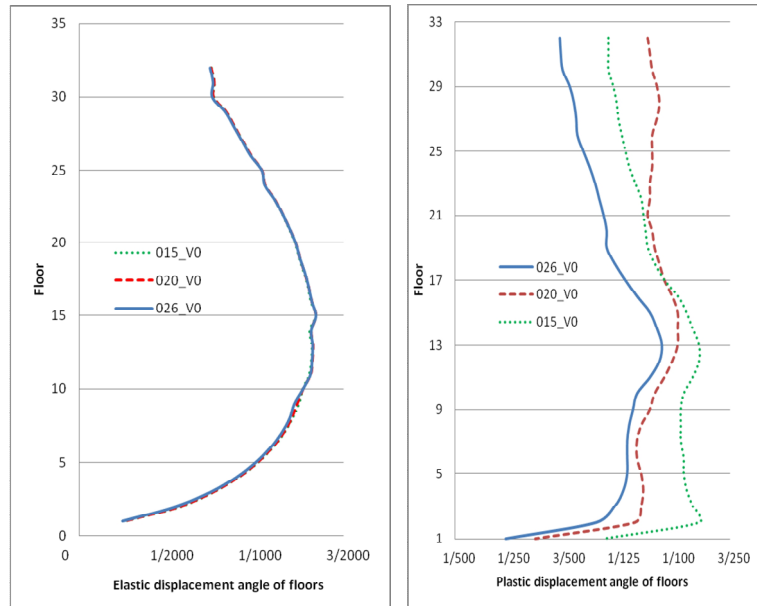


Fig.4 Envelopes of displacement angle

It can be seen that spectrum method presented nearly the same results of displacement angles for three models, but the differences of plastic displacement angles are very significant and it proved that the structure, which has better stiffness of frames, could exhibit better performance under expected rare earthquakes.

The time-history of the 13th floor is also shown in Fig.5. The results show that time-histories could keep coincident before columns being damaged seriously and the curve of model C deviated from the other two models as its columns being damaged.

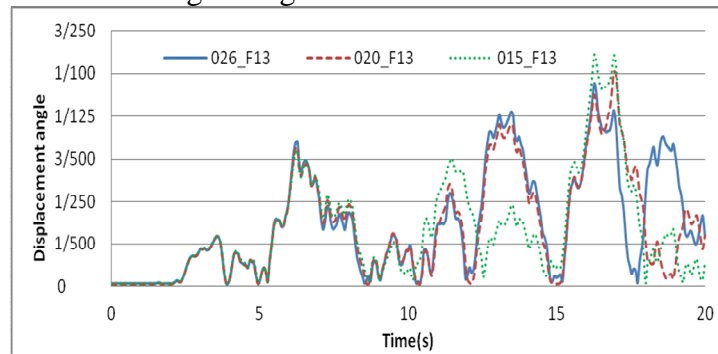
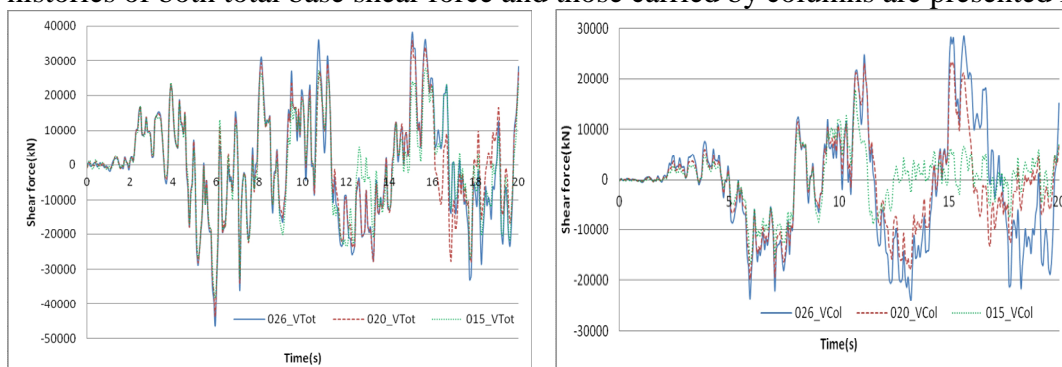


Fig.5 Time-history of displacement angle of 13th floor

3. Shear forces at base

Time-histories of both total base shear force and those carried by columns are presented in Fig.6.



(a) Total base shear force

(b) Shear force of columns

Fig.6 Time-history of shear force along x-direction

It can be seen that the structure may exhibit different dynamic performance after the damage of frames.

4. Overturning moments

Time-histories of overturning moment shown in Fig.7 are similar to the results of shear force shown in Fig.6. model C exhibited different property as the framed being damaged after ten seconds.

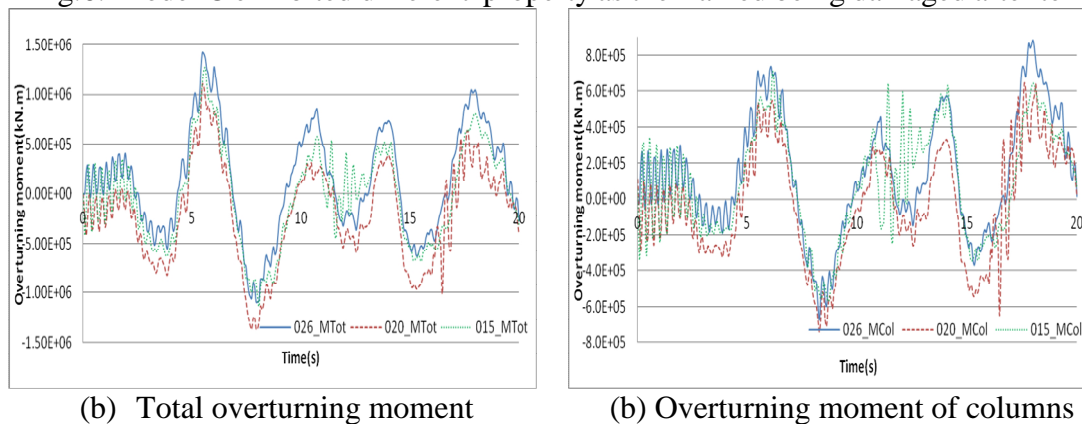


Fig.7 Time-history of overturning moment along x-direction

Conclusions

In Chinese codes, principle of 0.2V0 is one of the most important concepts of multi fortification lines for frame-tube structures under expected rare earthquakes. Numerical methods were used for simulating the principle of 0.2V0 for frame-tube structure with three similar models, in which the shear forces carried by columns were 0.26V0, 0.20V0 and 0.15V0 respectively. Numerical results show that model C with 0.15V0 was damaged earlier than the other two models because of the deficiency of lateral stiffness contributed by columns. It also proved that stiffness cannot be remedied by amplifying the load bearing capacities with more rebar, otherwise, the frames may not being competent for the second fortification line.

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