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STUDY ON TORSIONAL RESPONSE OF TALL BUILDING STRUCTURES WITH TRANSFER LAYER UNDER SEISMIC ACTION

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SUMMARY

The torsional response of tall building structures with transfer layer under seismic action is analyzed by the commonly used program PMSAP in China and the results are compared with those of the structures without transfer layer. The main factors affecting the torsional response of irregular tall building structures are discussed and the relationship between response and factors is analyzed. The effectiveness of the present code in China for tall building structures with transfer layer is checked, and some conclusions are drawn.

INTRODUCTION

In the middle of 1980s, a shear-wall structure system supported by large-space frame on the ground floor, first1y brought up by the Structure Institute of China Academy of Building Research, was designed in the seismic zones of intensity . Later, this structural system is applied to many tall buildings, and has developed rapidly. In some seismic regions, the transfer layer is designed in higher layer, usually from layer 3 to 6, even in much higher layer.

It is difficult to avoid the torsional response of general tall building structures under seismic action. Because the torsional response is caused by the strong ground motions, the asymmetric distribution of structural mass, the limitation of structural rigidity calculation and the limitation of design assumption, non-synchronism of damage in the torque members and occasional eccentricity of structure. Especially, as to the tall buildings with transfer layer, the discontinuity of the rigidity, internal force and the path of load transfer of the structure members nearby the transfer layer will appear and finally it is easy to form a weak layer near the transfer layer when the transfer layer is located in higher layer. It is worth investigating the difference of torsional response between the tall buildings with transfer layer and those without transfer layer.

ANALYSIS METHOD AND STRUCTURAL MODEL

In order to consider the response with translation and torsion coupled, a parameter, named the torsional response S_n, is defined as [1],

$$S_n = \theta r/u \tag{1}$$

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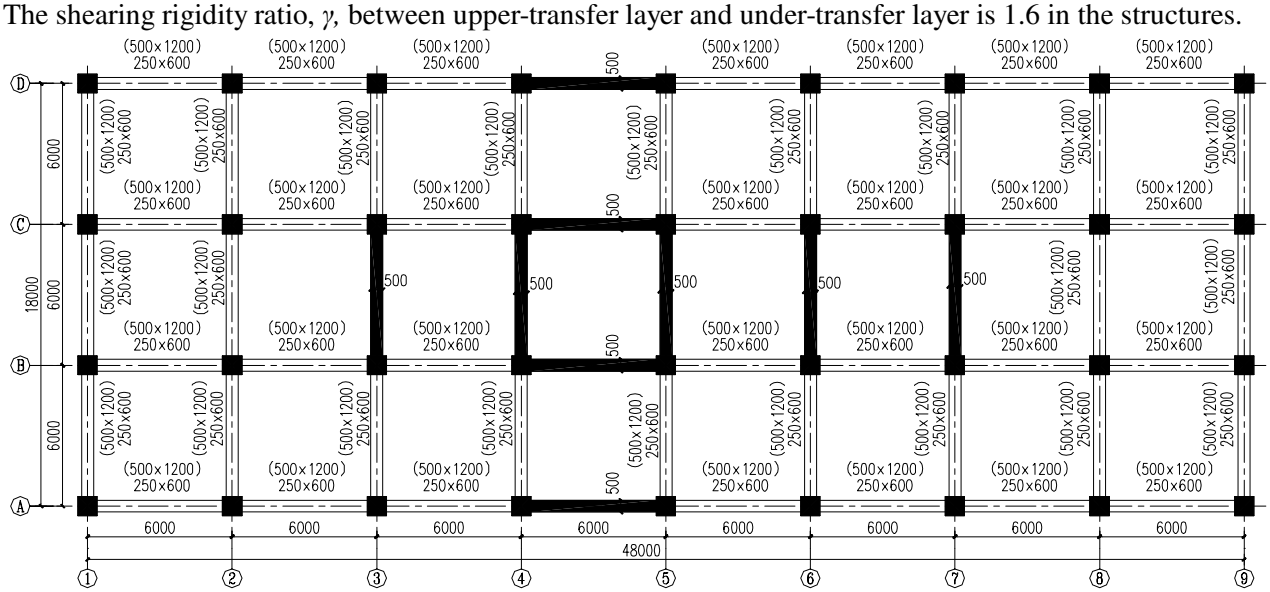
Where, θ is the angle of torsion, r is the gyration radius of the structure, u is the displacement of centroid at the top of building. In fact, the parameter also expresses the relative torsional response at the top layer of buildings. Equation (2) is given in this paper under the assumption of rigid floor, considering coupling response of the first-order lateral mode and the first-order torsional mode, and neglecting the influence of higher degree mode,

$$S_n = \varphi\left(\frac{e}{r}, \frac{T_t}{T_1}\right) \tag{2}$$

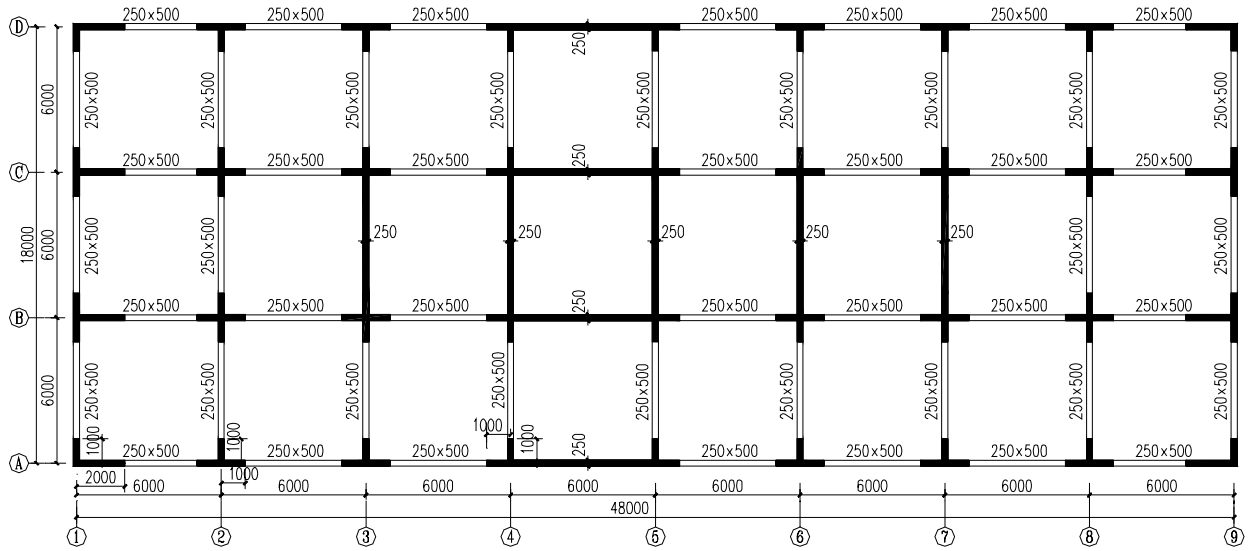
Where e/r is defined as the relative eccentric distance, and T_t/T_1 is the ratio of the first-order torsional period to the first-order translation period.

According to Equation (2), the torsional response S_n of general tall buildings is related to e/r and T_t/T_1. However, the torsional response S_n of tall buildings with transfer layer is not only related to e/r and T_t/T_1, but also closely related to the location of transfer layer. In the paper, the structure in Fig. 1 is analyzed by the response spectrum method for modal decomposition, using the commonly used structural analysis and design program PMSAP in China. According to the results, the torsional response S_n of tall buildings with transfer layer is compared with those without transfer layer under the seismic action. Because of the complexity of movement pattern, varieties in structure style and eccentric center style, the structure with regular horizontal and vertical shape, and with asymmetry in rigidity and mass, is chosen in the paper. Mass center of structure lies on a vertical line, and the rigidity center of structure lies on a another vertical line.

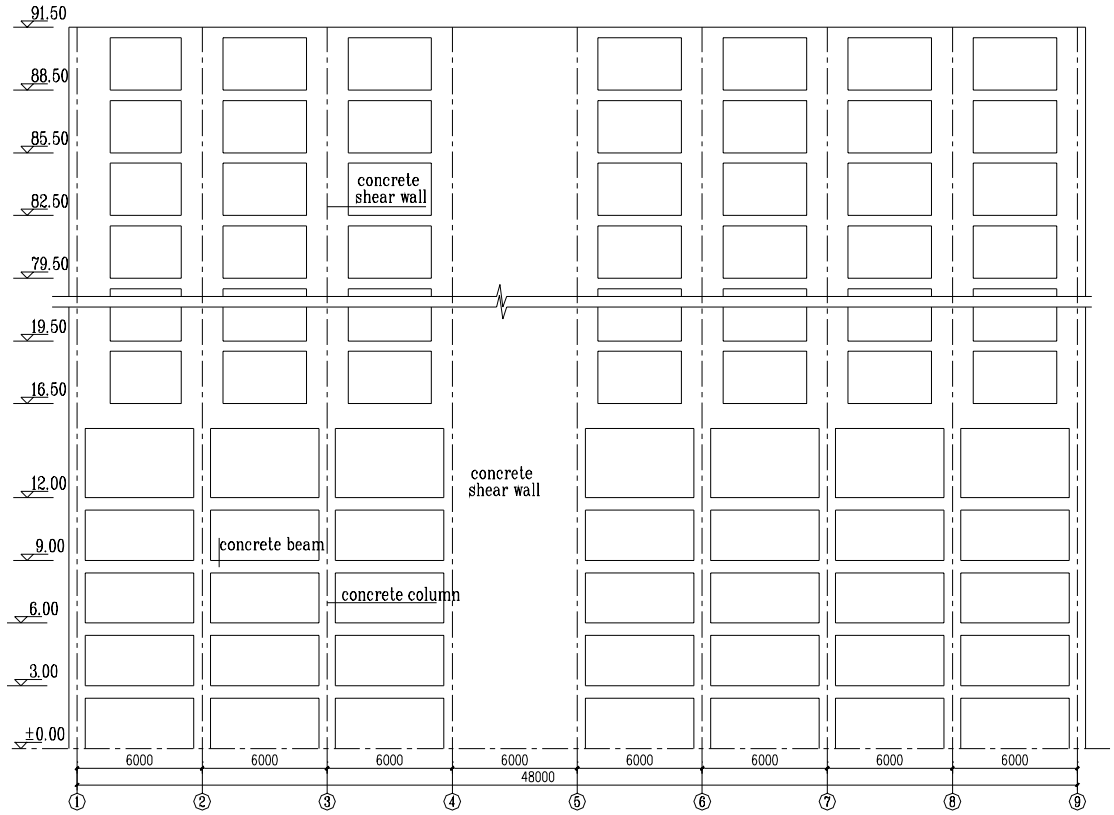
The height of structure with 30 layers in Figure 1(c) is 91.5m. The structure style of transfer layer and under-transfer layers is frame-supported shear wall, which consists of the floor shear wall and supporting frame. The plan of the transfer layer and under-transfer layers shows in Figure 1(a), in which the size of all transfer beams is shown in the bracket. In the transfer layer and under-transfer layers, the size of all columns is 1000mm×1000mm, the thickness of the floor shear walls is 500mm, and the design concrete strength of transfer layer and under-transfer layers is 19.1MPa. The plan of upper transfer layers is shown in Figure 1(b). In under-transfer layers, the thickness of the shear walls is 250mm, and the design concrete strength of upper-transfer layers is 14.3MPa. The height of layer is 3.0m except that the height of transfer layer is 4.5m. The slab thickness of layers is 120mm except that the thickness of transfer layer is 200mm. The shearing rigidity ratio, γ, between upper-transfer layer and under-transfer layer is 1.6 in the structures.



(a) The layout of floors under the transfer layer



(b) The layout of floors above the transfer layer



(c) The elevation view of the structures

Figure 1 The structures analyzed

In order to investigate the influence of the location of transfer layer on the torsional response, the location of transfer layer changes. To keep the total height of structure invariable, the number of the layers of frame-supported shear wall structure is increased and the number of layers of shear wall structure is decreased. The transfer layer is designed to be located in the first floor, fifth layer and tenth layer. In order to investigate the influence of the relative eccentric distance to the torsional response, the relative eccentric distance *e/r* varies from 0.1 to 0.6 by the method of changing the mass distribution of the

structure, at the same time, the value of T_t/T_l is 0.68. In order to investigate the influence of the ratio of the torsional period to the translation period to the torsional response, the ratio of the torsional period to the translation period T_t/T_l is determined 0.2, 0.3 0.4 and 0.5. At the same time, the ratio of the torsional period to the translation period T_t/T_l varies from 0.5 to 1.5 by the method of changing the rigidity distributing of the structure while the transfer layer is located in first and fifth layer.

FACTORS INFLUENCING S_n

Location of transfer layer

Some conclusions can be shown in Figure 2. Accordingly, the rule of the torsional response S_n is consistent with the relative eccentric distance *e/r*, whether the location of the transfer layer changes or not. Moreover, the torsional response S_n increases with the lifting of the transfer layer location. According to Table 1, when the relative eccentric distance e/r increases from 0.1 to 0.6, the increasing rate of the torsional response S_n decreases from 107.3% to 8.5% in the condition that the location of transfer layer changes from 1st layer to 5th layer. While the increasing rate of the torsional response S_n decreases from 62.4% to 3.3% in the condition that the location of transfer layer changes from 5th layer to 10th layer. It seems that the increasing rate of the torsional response S_n decreases by the lifting of the transfer layer while the relative eccentric distance *e/r* increases, even the increasing rate of the torsional response S_n drops rapidly with the lifting of transfer layer in the condition that the location of transfer layer is higher.

Table 1 The results of S_n

e/r	0.1	0.2	0.3	0.4	0.5	0.6
TL located in 1st layer	0.041	0.089	0.146	0.226	0.595	0.696
TL located in 5th layer	0.085	0.162	0.258	0.389	0.698	0.755
TL located in 10th layer	0.138	0.206	0.306	0.460	0.728	0.781
$Ratio_{5-1}$	107.3%	82.0%	76.7%	72.1%	17.3%	8.5%
$Ratio_{10-5}$	62.4%	27. 2%	18.6%	18.2%	15.6%	3.3%

NOTES: $Ratio_{5-1}$=(TL located in 5th layer-TL located in 1st layer)/ TL located in 1st layer;
$Ratio_{10-5}$=(TL located in 10th layer-TL located in 5th layer)/ TL located in 5th layer;
TL is representative of the transfer layer.

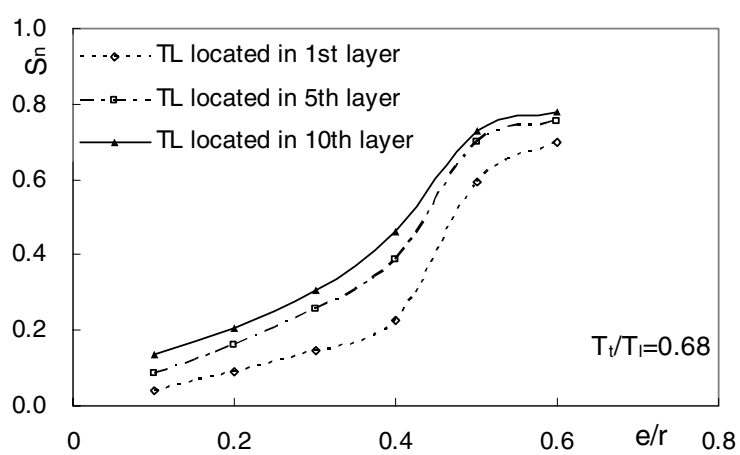


Figure 2 The correlation of S_n and e/r

Relative eccentric distance *e/r*

It can be seen from Fig. 2 that the torsional response S_n increases with the increasing of the relative eccentric distance *e/r*, when the relative eccentric distance *e/r* is less than 0.3. The torsional response S_n

increases sharply, when *e/r* is greater than 0.3. In a certain range, the higher value of *e/r* is, the more significant of the torsional response S_n is.

Ratio of the torsional period to the translation period

The following can be seen from Figure 3. First, the torsional response S_n of tall buildings with transfer layer increases with the increasing of the ratio of the torsional period to the translation period T_t/T_l in the condition that the ratio of T_t/T_l is less than 1.0. Second, the torsional response S_n will decrease with the increasing of the ratio of T_t/T_l in the condition that the ratio of T_t/T_l is more than 1.0. Furthermore, the torsional response S_n is usually small if the ratio of T_t/T_l is less than 0.5; while the torsional response S_n is likely to reach a higher value even if the relative eccentric distance *e/r* is very small, when the ratio of T_t/T_l is bigger than 0.7. Third, when the transfer layer located in the fifth layer, the value of torsional response S_n is bigger than those of the transfer layer located in the ground floor.

Compared with Figure4 given by Xu et al. [2], the rule of the torsional response S_n of tall buildings while transfer layer is located in first and fifth layer is consistent with that of tall buildings without transfer layer. In the paper, the torsional response S_n of tall buildings with transfer layer is bigger than the torsional response S_n in the Fig.4 when the ratio of T_t/T_l is less than 0.9. If the ratio of T_t/T_l is greater than 0.9, in the paper, the torsional response S_n is less than that in the Fig.4 only when the relative eccentric distance *e/r* is less than 0.3.

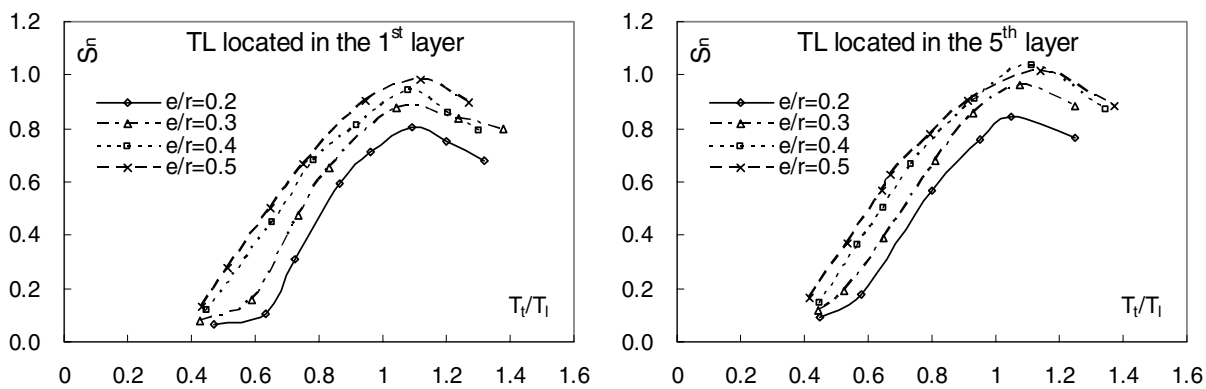


Figure 3 The correlation of S_n and *e/r*

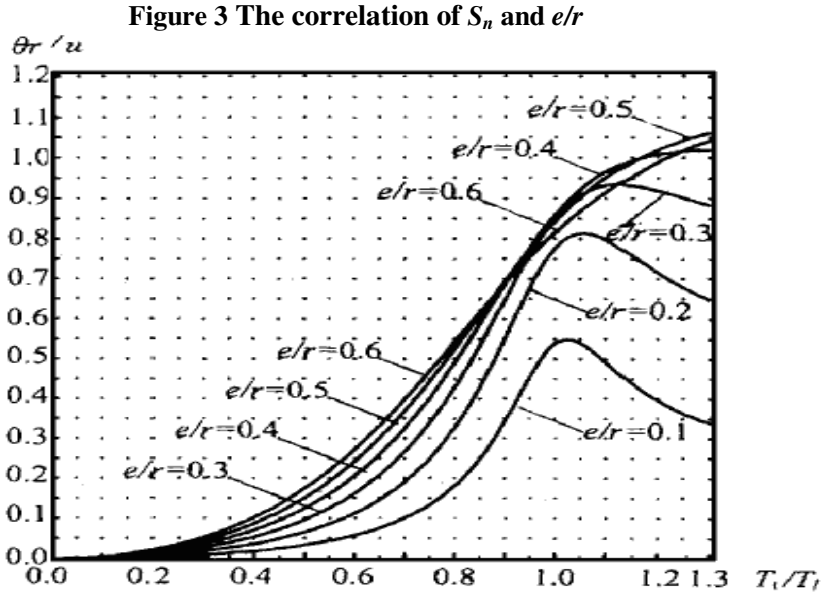


Figure 4 The correlation of S_n and *e/r* in Reference [2]

CONCLUSIONS AND SUGGESTIONS

From the above analysis, the following conclusions about the factors in the torsional response of tall buildings with transfer layer can be drawn,

(1) The torsional response of tall buildings with transfer layer is relative to the location of transfer layer, the relative eccentric distance e/r, and the ratio of the torsional period to the translation period T_t/T_1;

(2) The torsional response increases with the lifting of the transfer layer;

(3) The torsional response increases with the increasing of the relative eccentric distance e/r; and

(4) The torsional response of tall buildings with transfer layer increases with the increasing of the ratio of the torsional period to the translation period T_t/T_1 on condition that the ratio T_t/T_1 is less than 1.0. While the torsional response decreases with the increasing of the ratio of T_t/T_1 on condition that the ratio of T_t/T_1 is more than 1.0. Second, the torsional response S_n is usually small if the ratio of T_t/T_1 is less than 0.5; while the torsional response S_n is likely to reach a bigger value when the ratio of T_t/T_1 is more than 0.7, even if the relative eccentric distance e/r is very litter. Third, when the transfer layer located in the fifth layer, the value of torsional response S_n is bigger than those of the transfer layer located in the ground floor.

According to the above conclusions, it is necessary to avoid the higher location of transfer layer, to reduce the increasing of the relative eccentric distance, and to pay more attention to the ratio of T_t/T_1 in the course of tall building design. In the paper, the ratio of T_t/T_1 must be less than 0.9 given in the Code for Seismic Design of Tall Buildings, GB50011-2001, [3] and in the Technical Specification for Concrete Structures of Tall Buildings, JGJ3-2002, [4] in China.

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