

Study of Monolithic High-rise Buildings with Transfer Floors under Progressive Destruction in the Nonlinear Formulation

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SUMMARY:

High-rise buildings have recently become the essential form of building structure constructed extensively in densely populated countries or urban areas. Along with innovative building materials and construction methods, construction of high-rise buildings has commonly increased. Monolithic high-rise building with transfer floors is one of the practical methods in construction of tall buildings. This research is trying to identify and investigate risk assessment in analyzing high-rise buildings with transfer floors utilizing parallel-structure systems.

The main objective of this article is to find a solution to control the stability of high-rise structures after occurrence of any events leading to inefficiency of main structural members. Such structures are considered with all possible conditions, events and risk analysis and finally, the achieved results to find the best possible solution will be presented.

Keywords: transfer floors, drift angle, progressive destruction, deflection.

1. INTRODUCTION: BUILDING WITH TRANSFER FLOORS

Buildings with "transfer floors" belong to the type of asymmetric systems with variable rigidity. In these examples, the research and design of real objects offer some new transitional structures (Figs. 1, 2).

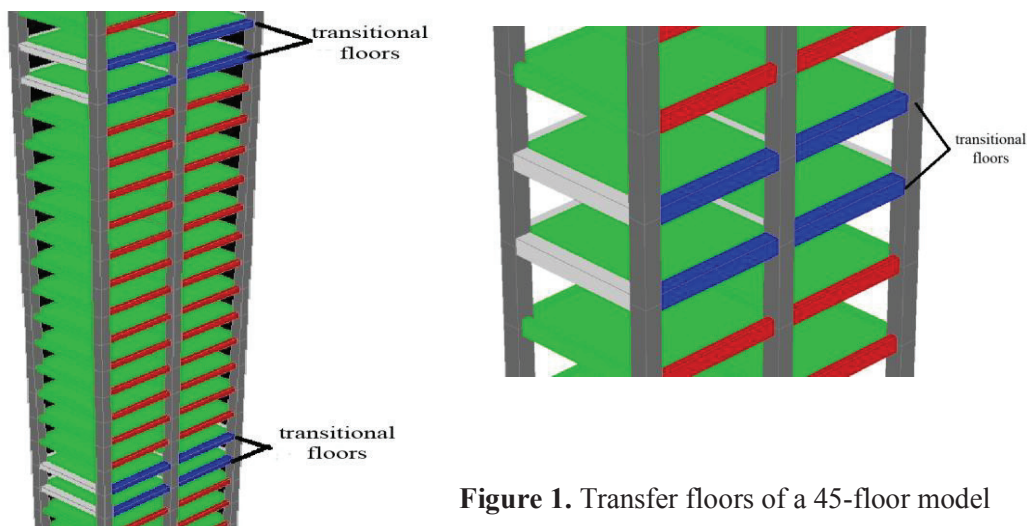


Figure 1. Transfer floors of a 45-floor model

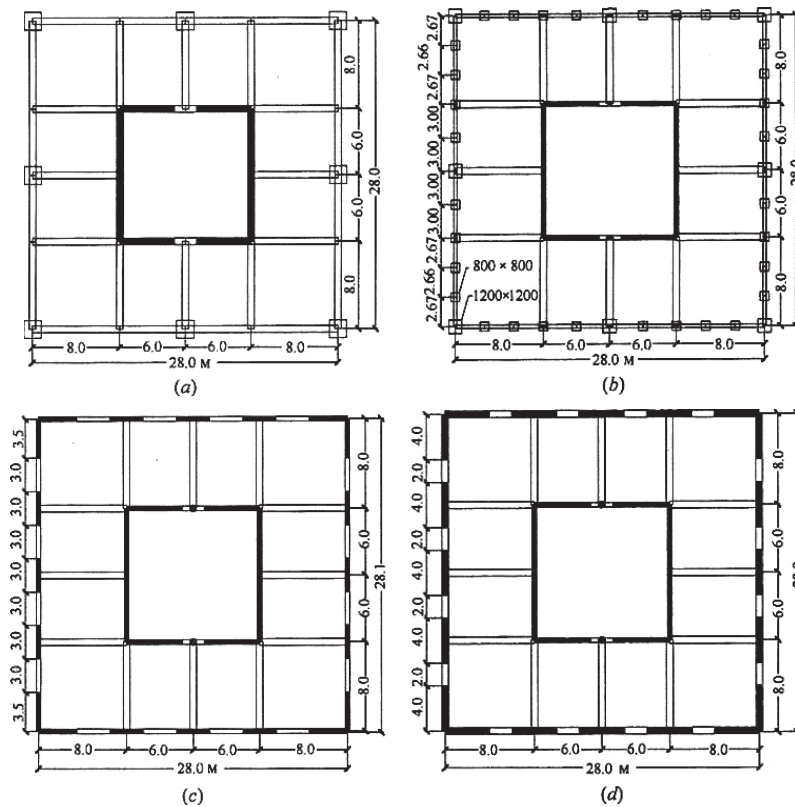


Figure 2. Building design with rigid core: a - the lower part of the design plan for the transitional floor; b – the higher part of the design plan for the transitional floor (type A); c - the higher part of the design plan for the transitional floor (type B); d - the higher part of the design plan for the transitional floor (type C);

In analyzing the effect of the height of the transitional floor, the height of the floors under transition was increased and decreased, respectively, compared to the height of floors above the transitional floor. The overall building height remains constant. The research was conducted to identify the main factors influencing the design of earthquake resistance of the high-rise building: the height of the transitional floor installed and the ratio of the vertical rigidity of the transitional floors to the rigidity of the upper and lower floors.

2. ESTABLISHMENT OF HEIGHT OF TRANSITIONAL FLOORS.

The Change of the building floor drift angles, depending on the location of the transitional floors (from 1st to 7th floor) is shown by the curves in Fig. 3. The dependence of the drift angle between floors at the location of the transitional floors at different levels is shown in Fig. 4.

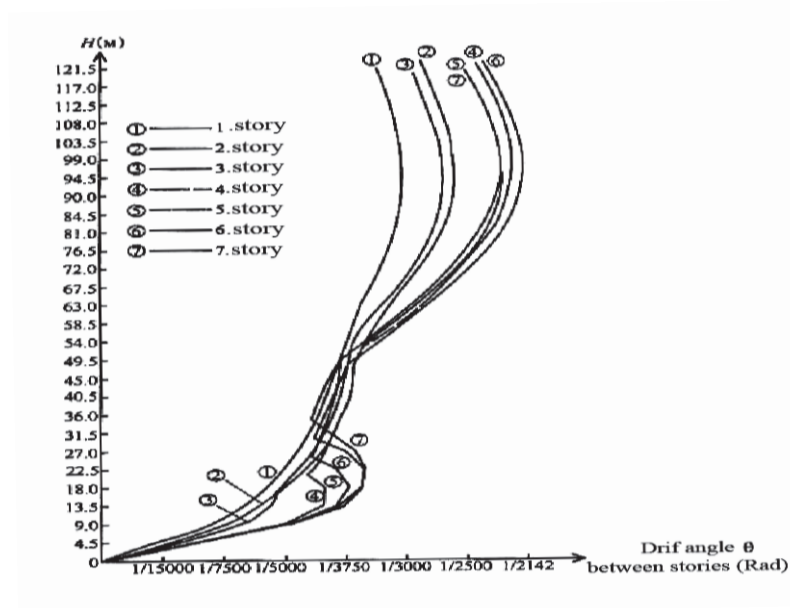


Figure 3. Diagram of the design floor drift angles

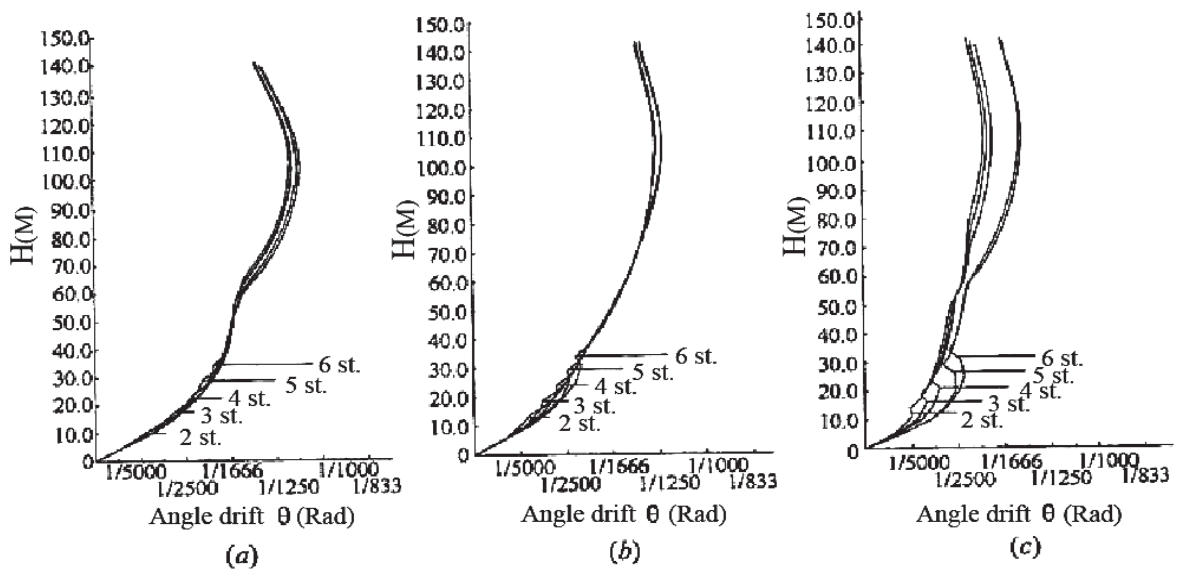


Figure 4. The dependence of the drift angle (θ) between floors at the location of the transitional floors at different levels: a- type A , b- type B, c- type C

Table 1 shows the comparative analysis of the shear force depending on the location of the transitional floors.

Table 1. Comparison of changes in shear force when installing the transitional floor on the 2nd and 5th floor.

	Location of transitional floor	Shear force of the outside frame, Q_o			Shear force of the inside frame, Q_i		
		top floor	transitional floors	lower floor	top floor	transitional floors	lower floor
Type A	2	0,34-0,39	0,13-0,17	0,06-0,07	0,60-0,65	0,83-0,87	0,93
	5	0,53-0,58	0,19-0,25	0,03	0,41-0,46	0,74-0,80	0,97
Type B	2	0,72-0,79	0,15-0,18	0,06	0,2-0,27	0,82-0,84	0,94
	5	0,9-1,0	0,19-0,21	0,02	0-0,17	0,78-0,80	0,98
Type C	2	0,78-0,86	0,11-0,16	0,07	0,14-0,2	0,84-0,88	0,94
	5	0,96-1,08	0,14-0,18	0,02	-0,10-0,1	0,81-0,93	0,98

The past studies have shown that the location of the transitional floors above the drift angle between floors in the level of the transitional floor and the distribution of shear force change more significantly.

3. TRANSVERSE RIGIDIY OF BUILDING ABOVE & BELOW TRANSITIONAL FLOORS.

The design should regulate the height of the transitional floor, including the drift angle between the transitional floor and the upper and lower floors and the change of shear force in the transitional floor. Fig. 5 shows the change in the relative angle between the transitional drift, the upper and lower floors (θ_1/θ_2) and relative displacement (V_1/V_2), depending on the transverse rigidity of the transitional floors to the rigidity of the upper floor, for the location of the transitional floor on the 2nd, 3rd, 4th, 5th, 6th floors. From the analysis of dependences presented in Fig. 5, we can conclude that for buildings with shear-wall at a constant location of the transitional floors, if the height of the lower floor under transition increases with decreasing ratio of the transverse rigidity of the transitional floors to the rigidity of the upper floors, the relation θ_1/θ_2 and V_1/V_2 increases.

Table 2. analyzes the values of shear force in the construction of floors above and below the transition of the 5th floor, depending on the design options of ten floors of the transition.

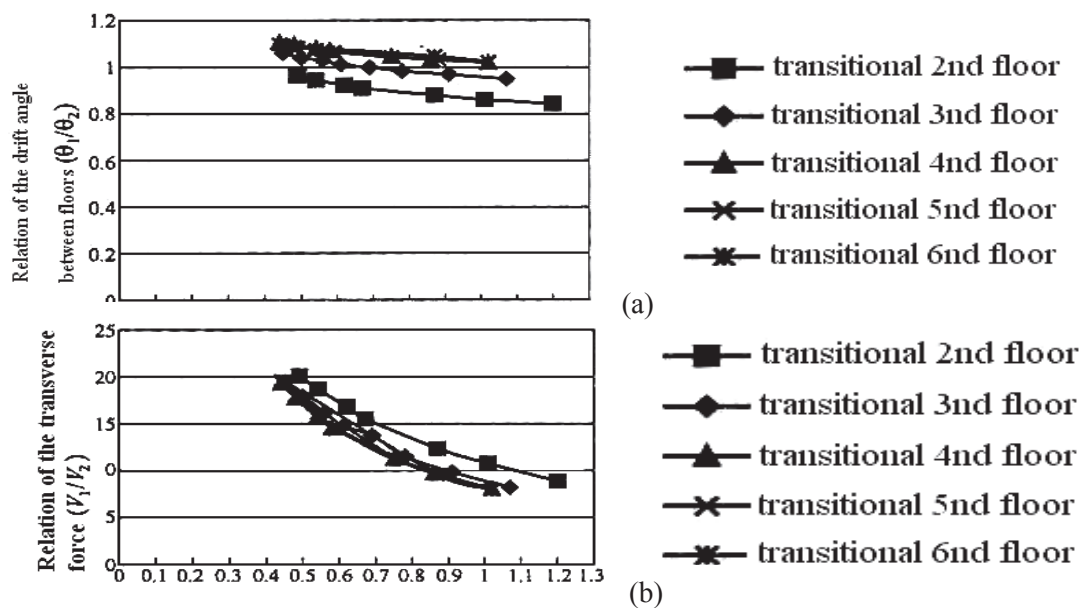


Figure 5. Relation of the vertical rigidity of the transitional floors to its top floor.

Table 2. The transversal force on the inner and outer core frame design rigid

	Shear force of the outside frame, Q_0			Shear force of the inside frame, Q_0		
	6 th floor	5 th floor	4 th floor	6 th floor	5 th floor	4 th floor
A1	0,532	0,221	0,030	0,457	0,774	0,967
A2	0,573	0,246	0,031	0,415	0,748	0,966
A3	0,553	0,192	0,029	0,435	0,802	0,968
A4	0,584	0,212	0,030	0,402	0,781	0,966
B1	0,899	0,189	0,019	0,173	0,803	0,977
e ₂	0,999	0,205	0,021	-0,030	0,787	0,975
C1	0,964	0,168	0,014	0,013	0,823	0,981
C ₂	1,057	0,180	0,016	-0,083	0,811	0,980
C ₃	0,980	0,139	0,016	0,005	0,852	0,979
C ₄	1,076	0,165	0,019	-0,094	0,930	0,978

From these results it is evident that the rigidity of the outer core frame rigidity of the upper part of the building provides strong effect on the rigidity of the building in the whole, and consequently on the distribution of shear force. If the outer frame of the building is designed as a framework, in general cases, the variation of results is often a change in the transverse rigidity of the building, but there is less variation in the shear force. The ratio of the transverse rigidity of the transitional floors to the rigidity of the upper floor and the dependence of V_1/V_2 for the location of the transitional floors on the 2nd and 5th floors are shown in Fig. 6.

Analyzing the dependence presented in Fig. 6, it shows that for the construction of the frame with the transitional floors with decreasing ratio of the transversal rigidity of the transitional floors to the rigidity of the upper floors of the relation θ_1/θ_2 and V_2 / V_1 increases. The ratio of the equivalent rigidity of the transitional floor, the ratio of the equivalent rigidity of the floors above and below the transitional floor can be used in Figure 7 and the following formula:

$$\gamma_e = \frac{\Delta_1}{\Delta_2} \cdot \frac{H_2}{H_1}, \quad (1)$$

Where H_1 and H_2 - are heights of the computational model of the lower and upper parts of the building $H_1 > H_2$, Δ_1 - Displacement of the lower part of the building at H_1 height, Δ_2 - Displacement of the bottom part of the building at H_2 height.

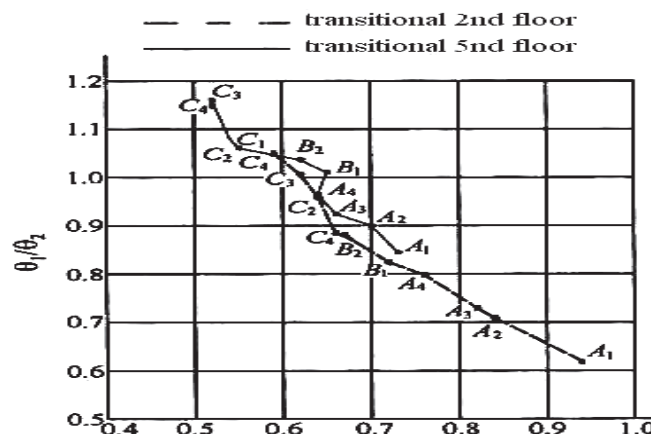


Figure 6. The ratio of the vertical rigidity of the transitional floors to its upper floor

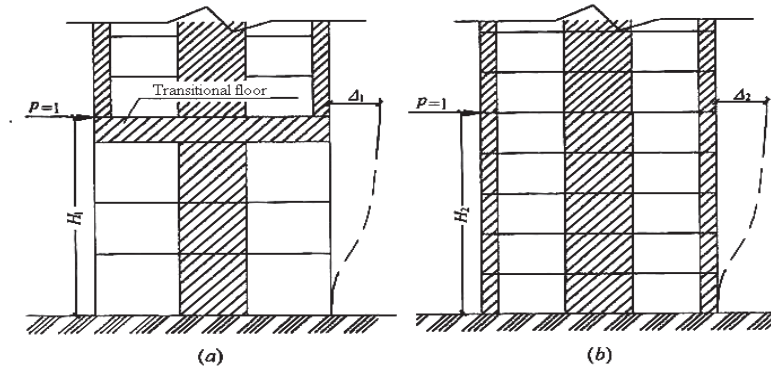


Figure 7. The computational model to simulate the equivalent rigidity of the building above and below the transitional floor: a - a computational model - the design of the lower floors of the transitional floor; b - the estimated model 2 - the design of the upper floors of the transitional floor.

For different cases the location of the transitional floors from the 1st to 7th in the direction Y, the ratio of shear rigidity ($K^{\text{lower}} / K^{\text{top}}$) and the ratio of the equivalent transversal rigidity and γ_e construction of upper and lower parts of the story about the transitional floor are given in Table. 3. The equivalent rigidity of floor is taken as the ratio of the shear force of the floor to the shear rigidity between floors. The ratio of the equivalent rigidity γ_e for the construction of the upper and lower floors of the transitional floor is the source of the static-geometric characteristics of the building.

Table 3. The ratio of the rigidity of floors in the direction of γ in the position of the transition floor

Number of floor	1st floor	2nd floor	3rd floor	4th floor	5th floor	6th floor	7th floor
Ratio of rigidity							
The ratio of the shear rigidity	1,76	1,76	1,76	1,76	1,76	1,76	1,76
The ratio of the transverse rigidity	1,16	0,77	0,69	0,67	0,66	0,66	0,66
The ratio of the equivalent rigidity	-	1,348	-	1,468	-	1,49	1,534

By analyzing data from Table 3, we can conclude that with the increase of the ratio of the transitional floor, shear rigidity is almost unchanged, the ratio of shear rigidity decreases and the ratio of the equivalent rigidity increases. Therefore, for buildings with shear-walls and transitional floors, where the upper floors are supported by columns and beams, located above the 1st floor, changing the attitude of equivalent rigidity is the best way. To further investigate the relation of equivalent rigidity, the size of the floors above and below the transitional floor is regulated. In this case, respectively, the equivalent rigidity ratio changed γ_e . From the research, the variation of the drift angle between the floors above and below the transitional floor (θ_1, θ_2) and the change of internal forces (v_2 & v_1) in the columns of floors above and below the transitional floor are studied when the equivalent rigidity is γ_e . To obtain more complete data, variants of the location of the transitional floors on the 2nd, 3rd, 4th, 5th and 6th floors were considered. The calculation results are shown in Fig. 8.

At a fixed position of the transitional floor (see Fig. 8, a) the increasing ratio of equivalent rigidity ratio γ_e -angles θ_1/θ_2 increases (at $\gamma_e < 1$, $\theta_1/\theta_2 < 1$). In the fixed position, the equivalent rigidity of the transitional floor rises and at the same time increases the ratio of drift angles θ_1/θ_2 . With an increase of equivalent rigidity to values $\gamma_e < 1.3$, the ratio of drift angles θ_1/θ_2 increases. Therefore, for the

construction of buildings with shear-walls and the ratio of equivalent rigidity γ_e almost characterized by varying the drift angle between the floors above and below the transitional floor. At a fixed position of the transitional floor (see Fig. 8, b), if the ratio of the equivalent rigidity γ_e increases, then the ratio of shear forces V_2/V_1 also increases. When the equivalent rigidity $\gamma_e < 1$, then for any position of the transitional floor ratio V_2/V_1 practically unchanged. If $1 < \gamma_e < 1.3$ and the position of the transitional floors changes so the ratio V_2/V_1 varies only slightly. But with regard to $\gamma_e > 1.3$ the value of V_2/V_1 increases significantly, it means that there is a sharp change in shear force from the floors above the transitional floor to the underlying floors, resulting in overlap of the transitional floors have great transversal forces.

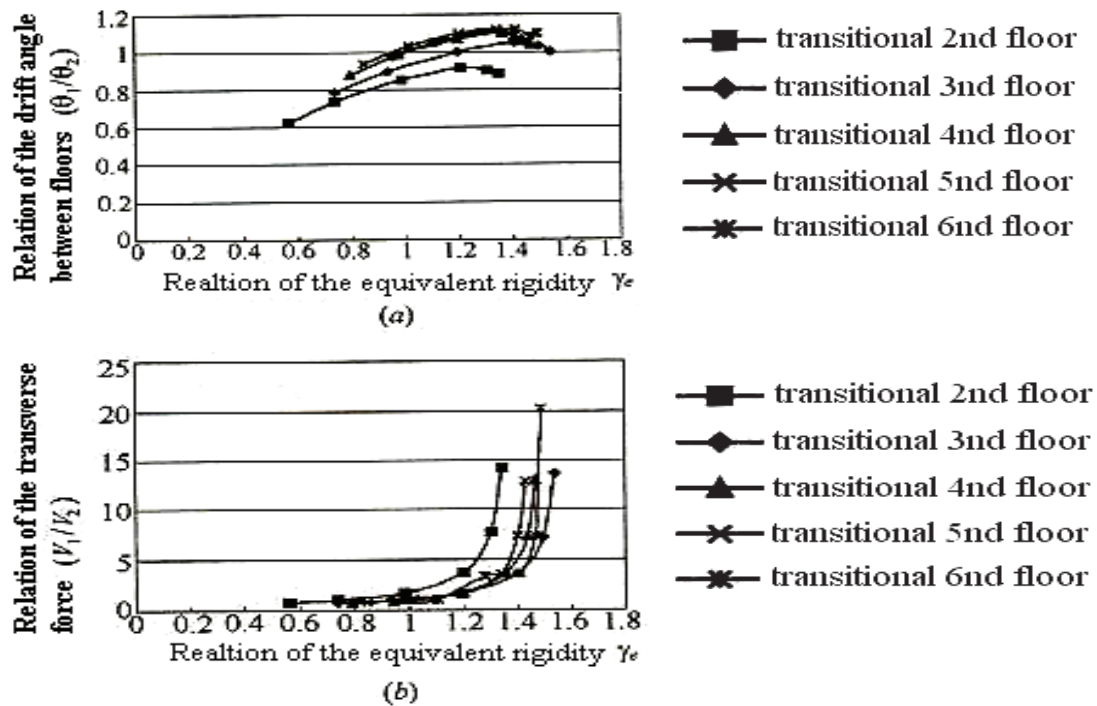


Figure 8. Dependence of the ratio of equivalent rigidity. a - the ratio of the drift angle; b - the ratio of drift forces

From the above analysis we see that for the construction of buildings with shear-walls and transitional floors of the ratio of equivalent rigidity of the upper and lower parts of the building is largely affected by the change of the drift angle between the floors above and below the transitional floors. This is the main factor affecting the seismic stability and resistance to progressive collapse of buildings.

4. CALCULATION EXAMPLE FOR A MONOLITHIC 45-STOREYS FRAME ON THE PROGRESSIVE DESTRUCTION

4.1. Research Problems

At the present time the issues of progressive destruction of the high-rise public buildings are becoming more important. There are many papers devoted to this interesting topic. Among them, we can find estimates for one-storey high-rise frame model, the effects arising from local injury. Various studies have indicated that one-storey model is used only for buildings up to 7-10 floors. A dynamic behavior of the taller buildings in the local lesions is unknown. Here we note another important role of dynamic effects.

However, the consideration of the impact of these dynamic factors with an increase in the number of storey of the building is not much understood. In addition, the practice of design of reinforced concrete structures typically do not perform complex dynamic calculations. Therefore simplified methods are required for static analysis of progressive failure. In the U.S. regulations [179.183] a simple method of calculation is proposed, but, as shown, it leads to unnecessary costs of materials and is not economical. Thus, the purpose of this work is to investigate the influence of dynamic effects on the operation of monolithic multi-storey frames with local lesions.

In line with this objective we are given the following tasks of research:

1. Identify the characteristics of the damaged high-rise frames.
2. Perform dynamic analysis of multi-storey monolithic frames in the elastic stage, the sudden removal of the columns of the first floor in a common framework and compared with the building of the transitional floors.
3. Develop a method for dynamic analysis of multi storey frame in a nonlinear formulation.
4. To investigate changes in the coefficient of dynamic load with increasing height.
5. To develop a simplified method of calculating the resistance to progressive deterioration in multi-storey frames.
6. On the basis of these results to develop a simplified method of design elements of the framework and on this basis to recommend suitable design solutions.

To study the dynamics of the load factor K_{dv} frames with different number of storey shall use the following data:

The building is monolithic frame, two-span. Overlap of prefabricated ribbed plates with a thickness of 25 cm and thickness of the transitional floors 50cm. Number of floors varies from 1 to 45.

The size of the grid columns 6 x 6 m, load (normative):

Continuous: 4.9 kN/m^2 ; long: 0.9 kN/m^2 .

As a result of the design of the building intact:

- Columns: 70x70 cm, heavy concrete B25, A400 grade fittings (A-III) varies depending on the number of floors.
- Beam of transitional Floors with size of 60x60 cm - Heavy concrete B30, $R_{bn} = 22,0 \text{ MPa}$, initial modulus of elasticity $E_b = 29\,000 \text{ MPa}$ reinforcement A400 (A-III): $R_{sn} = 400 \text{ MPa}$; $E_s = 200\,000 \text{ MPa}$.
- Reinforcement of the support sections: working the upper armature: $8 \varnothing 25 \text{ AS} = 39.27 \text{ cm}^2$, lower fittings: $\text{AS } 8\varnothing 22 = 30.41 \text{ cm}^2$;

Each frame of up to 45 floors with the above data was calculated on the number of applied loads instantly.

The values of a function of time is given up to two numbers after the decimal point. It provides an accurate determination of the destructive dynamic loading.

The behavior of the frame under the action of suddenly applied load, resulting in the SAP 2000 v14.2, is shown in Figure 9.

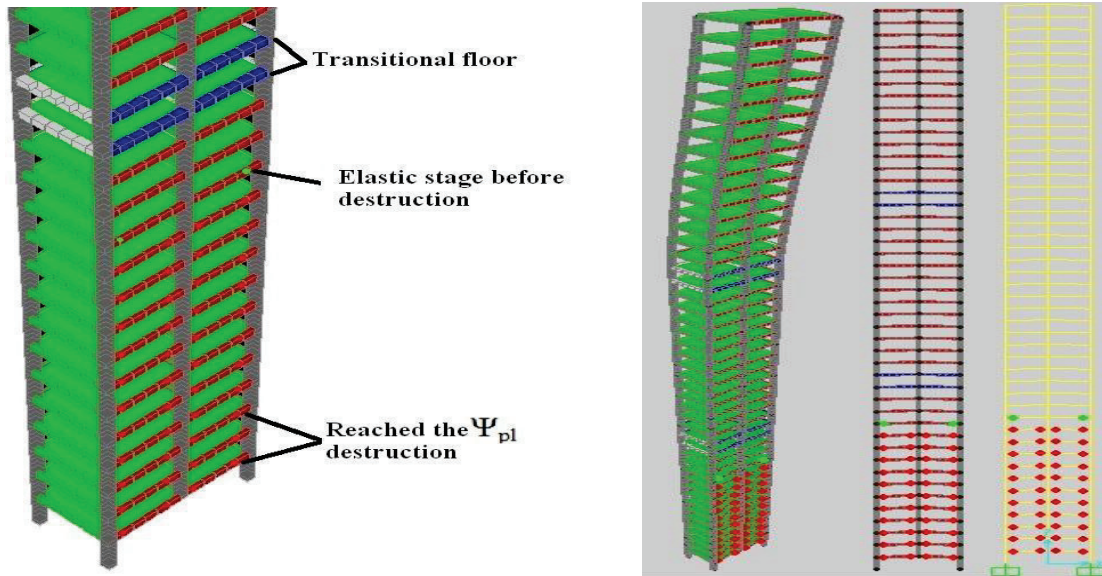


Figure 9. The behavior of the frame under the action of suddenly applied load

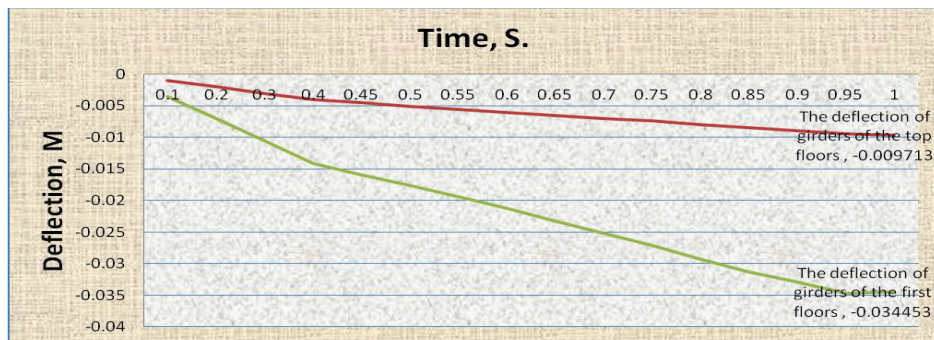


Figure 10. The deflection of girders of the first and the top floors with destructive load for a 45-storey frame with the transitional floors.

5. CONCLUSION

1. For the construction of buildings with shear-walls and transitional floors and construction of buildings with rigid core and transitional floors, the analysis of the drift angle between the floors above and below the transition is crucial and changes in internal forces. The main factors affecting the seismic stability of buildings: height of the transitional floor, the ratio of the equivalent rigidity of the upper and lower parts of the building relative to the transitional floor and the ratio of the transversal rigidity of bearing structures of the building, are identified. For the construction of buildings with the core rigidity and transitional floors, the main influencing factors are the rigidity of the outer frame of the transitional floor, floor mounting height of the transitional floor and rigidity of internal frame.

2. For the above two types of buildings with the height of the transitional structures of the transitional floor is the main factor affecting the seismic resistance of buildings. When the transitional floor is higher, the greater is the change in the drift angle between the floors above and below the transitional floor and greater is the change in internal forces. The design should limit the mounting height of the transitional floors.

3. Defined influenced by the ratio of the transverse rigidity of the transitional floors and upper floors in the seismic-resistant structures. For buildings with shear-walls, and the transitional floors, in which the position of the transitional floors rather low, limiting the ratio of shear rigidity, it is possible to limit the variation of the drift angle between the floors above and below the transitional floor and, accordingly, the change of internal forces.

4 .For the construction of buildings with shear-wall and transitional floors that are high enough, the restriction of the transversal rigidity of floors above and below the transitional floor is not enough. It must have the restriction of the equivalent rigidity of the upper and lower parts of the structure of the transitional floor. When larger is the ratio of equivalent rigidity γ_e design of the upper and lower floors of structures of the transitional, greater is the change in the drift angle between the floors above and below the transitional floor and, accordingly, the change of internal forces. The design should limit the ratio of the equivalent rigidity γ_e that it should be close to 1 and no more than 1,3.

5. For building structures with the core rigidity and transitional floors, if the outer frame of the building is designed as a framework, in general, there is no abrupt change in rigidity, but there is a sharp change in shear forces on the height of the building. The height of the installed transitional floor for such building, respectively, increases. The ratio of the equivalent rigidity γ_e in this case can be limited.

6. Relation transversal rigidity of the transitional floor of the transversal rigidity of the upper floors sometimes do not satisfy the accepted limits. For buildings with such designs, there is need to take some measures for their strengthening.

7. For the construction of buildings with the core rigidity and transitional floors, if the outer frame of the building is designed as a system of "shear wall-frame", the rigidity of a structural system and the distribution of shear forces is similar to the construction of "shear wall", supported by columns and beams.

REFERENCES

- Almazov V.O. (2010). Dynamics of progressive destruction multistory IED monolithic structure. Applied Research Associates for GSA (2003). Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Expansion Projects. Washington, D.C.
- Bazhenov YU. M. (1970). The concrete under dynamic loading.
- Gorodetskiy A.S. Batrak L.G. (2004). Calculation and design of structures of tall buildings of reinforced concrete.
- Popov N.N, Kumpyak O.T. Spitting B.C. (1190). Questions dynamic analysis of reinforced concrete structures. Tomsk: Publishing house of Tbilisi State University, 288.
- Popov N.N., Matkov N.G., Trekin N.N. (1986). Indirect influence of reinforcement on the deformability of concrete under static and dynamic loading . Concrete and reinforced concrete. № 8.-S.17-21.
- Powell, Graham, (2004). Progressive Collapse: Case Studies Using Nonlinear Analysis. SEAOC Annual Convention, Monterey.
- Pretlove, A.J., Ramsden, M. and Atkins, A.G., (1991). Dynamic Effects in Progressive Failure of Structures, International Journal of Impact Engineering, Vol.11, No.4, pp.539-546.
- Ross, Donald; (2004). Design of public high-rise buildings of multifunction .
- Sui Peifu, Fu Suei, Van Suikui, Siao Sunzgen, (2004). The design of modern high-rise buildings.
- Tamrazyan A.G. (2004). Peculiarities of high-rise buildings. Homebuilding, № 3 p.19-20.
- Tikhonov I.N. (2007). Reinforcing elements of monolithic reinforced concrete buildings.
- Tsai, Meng-Hao ; Lin, Bing-Hui . (2008). Investigation of progressive collapse resistance and inelastic response for an earthquake-resistant RC building subjected to column failure. Engineering structures, №30 pp.3619-3628.