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INFLUENCE OF FLOOR CONSTRUCTION TYPE IN COUNTERING PROGRESSIVE COLLAPSE OF BUILDINGS AND STRUCTURES

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Fig.1. Collapse of 8 storey monolith building in Savar (Dhaka District, Dhaka, Bangladesh)

Recently cases of chain collapse of buildings and structures became more frequent. Reasons leading to this statistics are considered to be design flows, assembly misfit, low quality operation (unskilled reconstruction, etc.) domestic gas explosions and terrorist attacks. (Fig.1)

Modern design standards for different building types include the requirements for protection against progressive collapse (PR) caused by the local collapse of one or more bearing elements as a result of non-project impacts.

The most efficient means for countering progressive collapse is the use of constructive systems with high degree of redundancy. Rationally chosen constructive decision of structural elements design can significantly reduce the cost of measures to counter the PC.

Significant role in countering the progressive collapse plays the floor structure. The most common design patterns for monolithic slabs are - flat slabs and slabs reinforced with beams.

This article discusses an approach to the analysis of floor structure, as well as a comparison of the efficiency of flat slabs and slabs reinforced with beams in case of a progressive collapse.

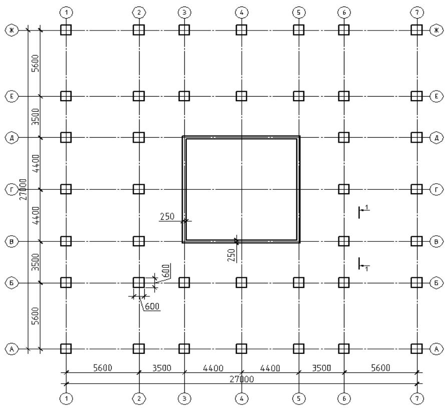


Figure 2. Typical floor plan

As a test object we have adopted a high-rise 40-storey frame building. The building a typical floor of is presented in the Fig.2.

The considered options of the floor system have following floors geometric characteristics (Fig. 3)

1. slabs reinforced with beams – beam height - 50 cm, width 30 cm, height of the slab - 16 cm
2. flat slaba - height of the slab - 20 cm

For a substantial analysis of the floor structure an appropriate model of its design is required.

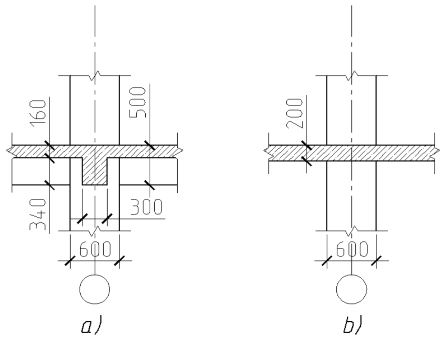


Fig 3. Floor design options

That is why while computing buildings progressive collapse model question of ratio of accuracy to labor intensity both during the preparation of modal and during the actual solution process (preparation of the system stiffness matrix, its subsequent decomposition and solution of the system of linear equations) arose. The latter is particularly significant when calculating the systems with account of the physical and geometric nonlinearities, since during the nonlinear analysis stiffness matrix computation happens at each step, and hence the procedure is repeated iteratively. For large models (amount of elements more than 100,000) being solved with the common desktop computers the time spent on the calculation of the stiffness matrix can vary from 3 to 30 minutes (depending on the amount of elements, spread of stiffness characteristics of the model, method adopted for solution of a system of linear equations, optimization methods embedded by the authors of software package), which ultimately leads to many hours pending the outcome of the calculation, which, in turn, may contain an error made at the stage of building FE model of the object. Therefore, it appears reasonable to follow the recommendation of paragraph D.2.3.6 SBR V.2.2-24: 2009 concerning the application of the principles of fragmentation on the model of the building. Unfortunately, there are very few certified in Ukraine programs, which have the built-in implementation of this principle. Implementation procedures of fragmentation we will consider on an example the "LIRA" software. To implement this method, we developed an approach, which consists of the following steps (Fig.4):

1. Modeling object with a coarse finite element mesh, and the columns elements located between floors are divided into 2 parts (obtained nodes are the position of fragmentation).
2. Carrying out a non-linear structural analysis for a coarse FE mesh (result – obtaining of values of displacement of intermediate column nodes).
3. Obtained displacements are stored in tabular form in the editor MS Office Excel
4. Detail modeling of object with fine finite element mesh
5. With the help of a specially designed procedure nodal displacement transfer from the scheme with the coarse mesh to the scheme with a fine mesh with

account of intermediate nodes is performed.

6. The obtained values are recorded in the source data file of "LIRA" software (or another computational complex, able to calculate construction on the specified displacement) in the form of information about the loads for load case 1 and 2 (the first load case - the initial state, the second load case - results of a progressive collapse)

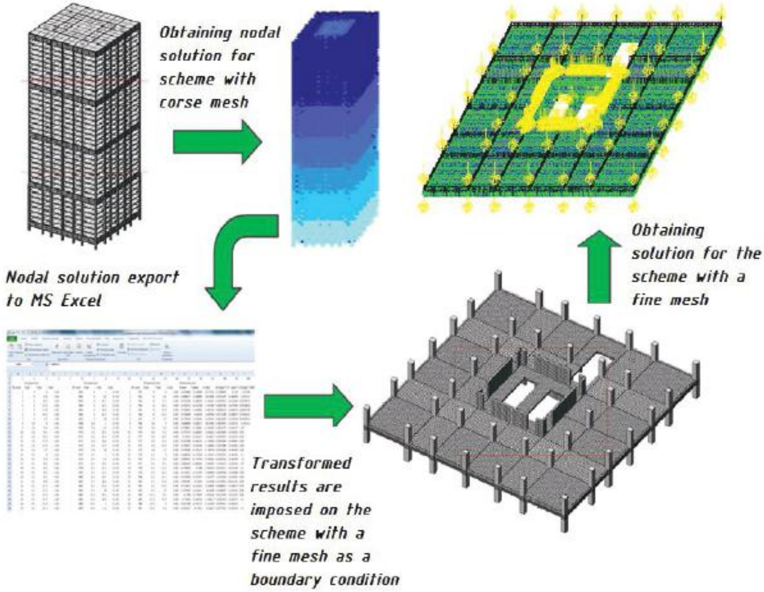


Fig 4. Fragmentation method implementation for «LIRA» software

The approach described above was used to compare two floor options stress-strain state in the case of progressive collapse.

A comparison of options (Fig. 5) showed that the scheme reinforced with beams is more rigid that determines the localization of displacement within a single floor cell.

The zone of influence of the column removal is within the limits of cells adjacent to the failed element (Fig.6), which meets the requirements for localization of the effects of destruction of structures, but the rigidity of the flat slabs is much lower than the rigidity of the beam model (up 25%).

Contour plots of shell moments state that for the case of beam floors forces occurring in the slab is significantly (2-3 times) less than the forces occurring in a flat slab (Fig. 7). This fact is explained by the role of the beams in the distribution of loads and tensions Nx, Ny in the footing plate zone.

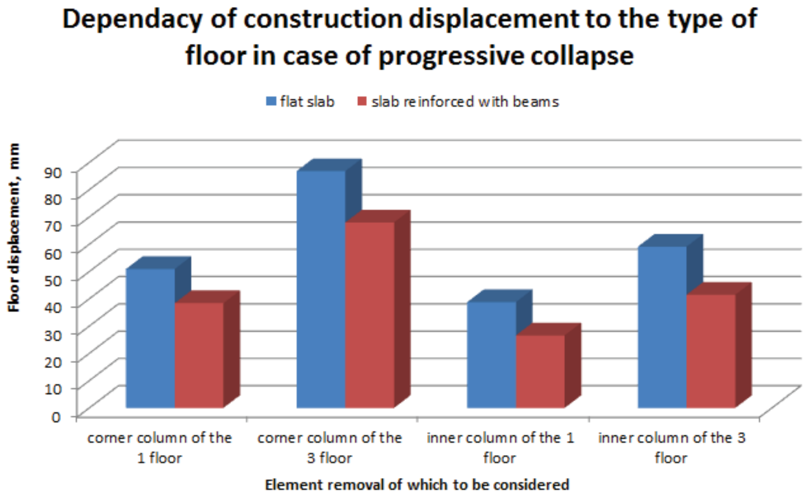
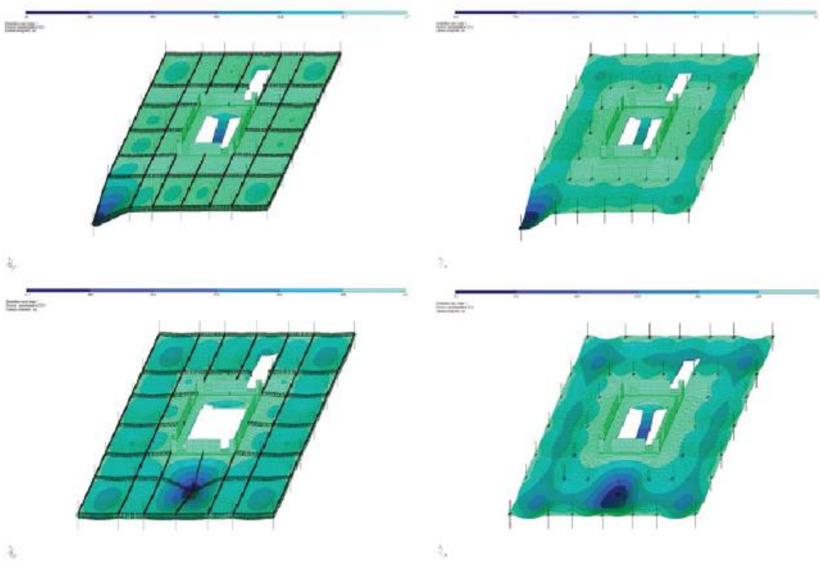


Fig.5. Dependency of construction displacement to the type of floor in case of progressive collapse



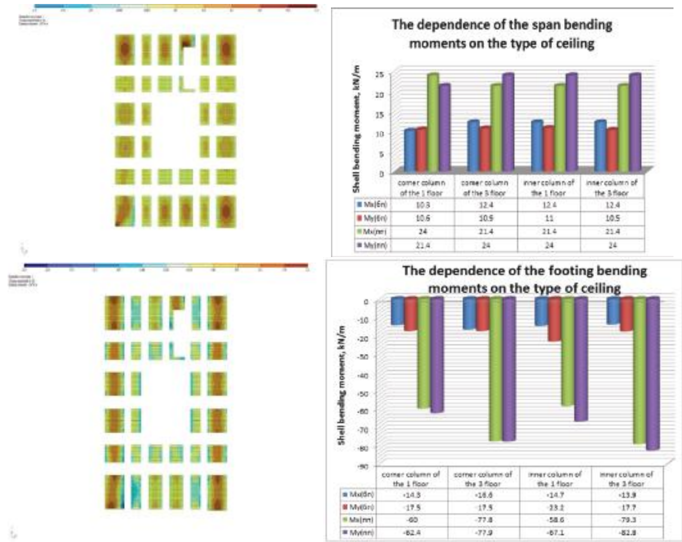


Fig. 7. Dependency of bending moments on the construction of the slab

Removal of the column leads to a change in schemes of work of slab. In case of the corner column removal the work scheme of the slab transforms to a cantilever one and in case of removal of the middle column slab span increases, wherein the footing zone turns into the span zone.

This fact explains the requirement of building regulations for need of continuous reinforcement at the top and bottom zones of slab. This design requirement creates the possibility of redistribution of effort in the construction in case of progressive collapse.

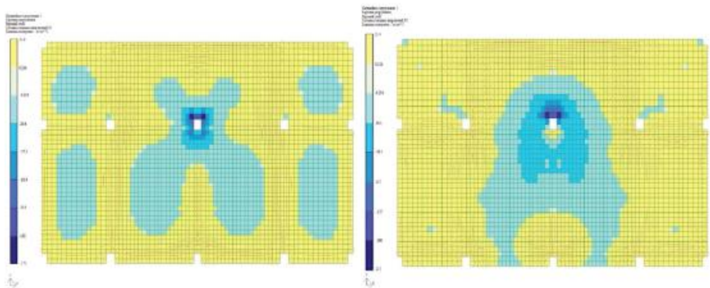


Fig. 8. Crack distribution in slabs adjacent to the damaged cells

Fig. 8 shows the pattern of cracks in the slab tension zone and the formation of plastic hinges in compressed elements adjacent to the columns. In systems with a beam model of floors cracks are located in the vicinity of the beams.

Results for the model of a flat slab indicate the need for more detailed study of the column – slab intersection zone. Model for a more comprehensive analysis of this assembly should include the capacity of reliable accounting of reinforcement in this zone.

Slab stress-strain state indicates of a significant damage of concrete of emergency cells and of part of the slab reinforcement achieving yield point. Despite this the load bearing capacity of slab is secured for the considered floor structures.

Let us consider forces occurring in the beam structure (Fig 9).

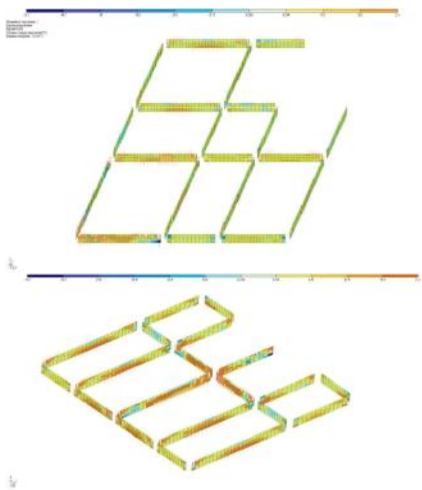


Fig. 9. Crack distribution in beams adjacent to the damaged cells

For beams situated outside of the damaged cells work scheme remains unchanged. For beams that are within the damaged cells scheme of work undergo certain changes:

- in place of compression the stretched zone may occur, and vice versa;
- in beams cracks caused by stretching in the concrete appear;
- in case of corner column removal plastic hinge is formed in the compressed zone.

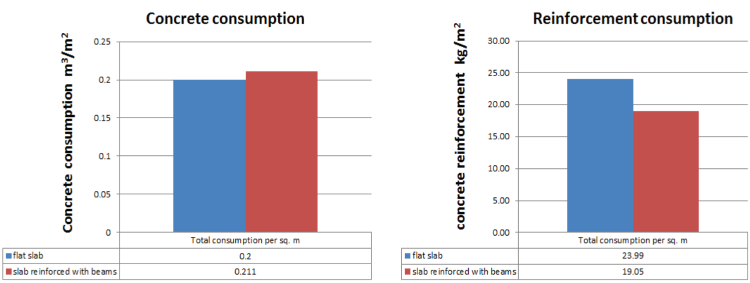


Fig. 10. Consumption of concrete m^3/m^2 and reinforcement kg/m^2

Also it should be noted that during developing the numerical model, an important role plays tacking into account transverse reinforcement of beams. Transverse reinforcement was modeled with beam elements which had common nodes (for joint work) with elements that were modeling concrete. It was found that incorporation of transverse reinforcement in the calculation allows to a greater extent involve longitudinal reinforcement located in the compressed zone of the cross-section.

Capitalizing on the calculation results the comparison of amount of needed materials have been conducted. Its results are presented in the Fig. 10 and tables 1. Table 1 presents information of material consumption for 1 floor with area of 651,56 m^2.

Table 1

	Concrete consumption, m^3		Reinforcement consumption, kg	
	flat slab	**slab reinforced with beams**	**flat slab**	**slab reinforced with beams**
Slab	130.31	104.25	15633.8 7	6282.51
Beam	0.00	33.17	0.00	6126.77
Total consumption per sq. m	0.20	0.21	23.99	19.05

Conclusions

1. The technique of implementation of the principle of fragmentation in the software complex «LIRA» with its approbation to the test object was devised.
2. Calculations explains paragraph 4.62 [1], which requires continuous reinforcement in the upper and lower zones a monolithic slab.
3. Found that both floor designs (beam model and a flat slab) may be used for buildings, designed in accordance to the progressive collapse calculation.

It was found that in case of progressive collapse beam model to be better than the flat slab, since the beams significantly reduce the stress and displacement of the floor construction. At the same time, the comparison by material consumption of floor options showed that the beam model is much more economical than flat slab model.

REFERENCES

1. ДБН В.2.2-24 2009 «Проектування висотних житлових і громадських будинків». К., Мінрегіонбуд України, 2006
2. Компьютерные модели конструкций – А. С. Городецкий, И. Д. Евзеров, Киев «Аакт» 2005
3. Рекомендации по защите высотных зданий от прогрессирующего обрушения. М., 2006.