

SCENARIOS FOR CHECKING THE PROGRESSIVE COLLAPSE OF REINFORCED CONCRETE DUAL SYSTEM FOR BUILDINGS

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Abstract. The objective of the study is a building structure, made of reinforced concrete in a dual system. The structure is a theoretical one but the dimensioning and the considered loads complies the technical regulations in force in Romania. Buildings' design to resist local damages without collapsing represents a relatively new concern among engineers. Some countries have technical regulations which include sets of rules regarding the design in order to prevent the progressive collapse phenomena. In Romania there are no such rules or specific recommendations. The goal of the study is checking the structure for progressive collapse on the basis of some scenarios proposed by the authors. For both studies the analysis remains in the linear elastic field. The FEM program used was SAP2000-V12.

Key words: progressive collapse, technical regulations, dual system.

1. INTRODUCTION

The event that triggered the expert's interest for this particular collapse development was the explosion caused by build up gas in the Ronan Point Building in London, in the year 1968. The failure represented the first accident considered as "progressive collapse". For about 10 years after this event, studies were conducted followed by the introduction in some design codes of commentaries and recommendations related with the progressive collapse phenomenon. The next events that boosted the research in this field were the terrorist attacks against the Alfred Murrah Building in Oklahoma and the Khobar Towers in Saudi Arabia. The third important moment was the terrorist attack on September the 11th from the United States of America.

At this moment there are several groups of experts – Joint Committee on Structural Safety (JCSS), The Working Committee COST Action "Robustness of Structures" – Brussels, Technical University of Hamburg, Building Research Establishment – London UK, National Institute of Standard and Technology USA,

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which are studying intensely and organizing scientific events about this topic. However, there is no mutual approach of the phenomenon and there is no consensus about the nomenclature and approach.

The object of the study is a dual system reinforced concrete structure. The structure is theoretical but the dimensioning and the considered loads complies the technical regulations in force in Romania. The building is nine stories high. The goal of the study is checking the structure for progressive collapse on the basis of some scenarios proposed by the authors. The calculus is performed in the elastical field.

The presented studies are part of a research activity developed in two main directions: (i) research within a PhD thesis studying the seismic design of the dual structures and (ii) research within a PN-II programme regarding the progressive collapse.

2. SEISMIC DESIGN ACCORDING TO THE IN FORCE ROMANIAN CODES

The office building has a ground floor and 8 storeys. It is a reinforced concrete structure. The outer covering is of curtain type wall, and the interior partitioning is made with gypsum wallboard. The flat roof will not be trafficable. The building is considered to be located in Bucharest.

The structure has 7 spans and 3 bays, occupying a horizontal surface of 665.00 sq m. The total height is 28.50 m.

The structure is seismically proof designed according to the Romanian technical regulations and has been evaluated in Serviceability Limit State (SLS) and Ultimate Limit State (ULS).

The three dimensional model is composed of one-dimensional elements – for beams and columns and two-dimensional elements – for floors and structural walls, Fig. 1.

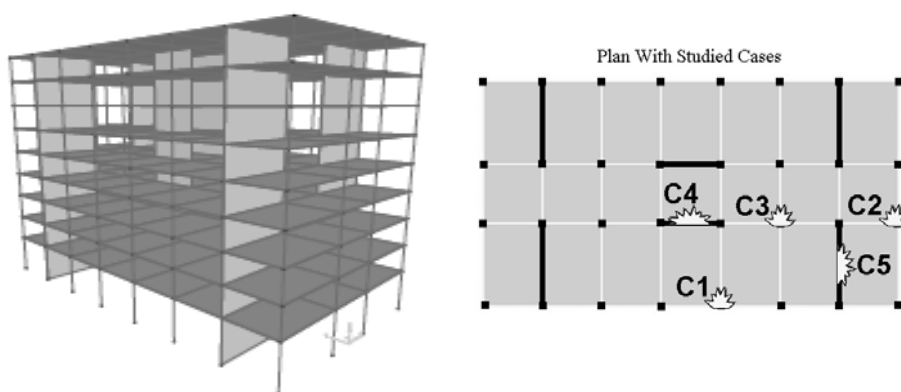


Fig. 1 – Calculation models.

The components of the mass considered in the dynamic study are the self weight of the structural elements and 40% of the live load. There have been considered enough vibration modes in order to mobilise as close to 100% of the total mass as possible. In the Figs. 2a, 2b and 2c are presented the fundamental vibration mode – longitudinal vibration ($T_1 = 0.97$ s), mode 2 – transversal vibration ($T_2 = 0.78$ s) and mode 3 – torsion vibration ($T_3 = 0.75$ s).

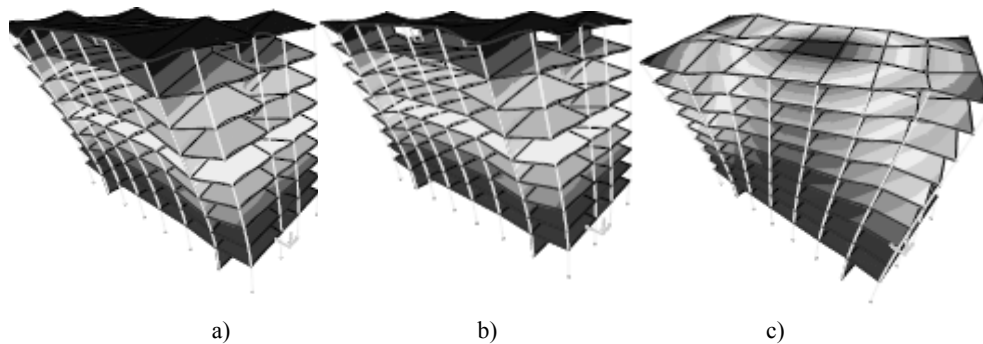


Fig. 2 – Structure inherent vibration modes:
a) fundamental mode; b) mode 2; c) mode 3 – torsion.

The seismic structural response, represented by efforts and displacements, is determined through a design response spectrums calculation. The maximum level relative displacement calculated is at the levels 2 and 3. The obtained values are below the admissible value for the relative displacement level [8]. Regarding the base shear force distribution ratio between the columns and the shear walls, it varies from 10% to 30% for the columns and from 90%–70% for the walls.

3. VERIFICATION FOR PROGRESSIVE COLLAPSE

Within the Romanian technical regulations there are no recommendations regarding the design or the verification for progressive collapse. Among the studied specialized technical literature, the most exhaustive set of recommendations was found in the paper GSA – Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects – June 2003 [10]. Even in this paper the recommendations are given for frame and shear walls structures separately. For the framed-structures there are recommendations regarding the position of the columns that have to be considered as being removed, Fig. 3a. For the structures with resistance walls are proposed scenarios concerning the position and the length of the walls to be removed, Fig. 3b.

For the dual structures there are no such recommendations. Therefore we had to propose our own approach of the way to start and develop the study for determining the sensibility of the structure to progressive collapse. As a result we have combined the recommendation for frame structure with those for shear wall structures.

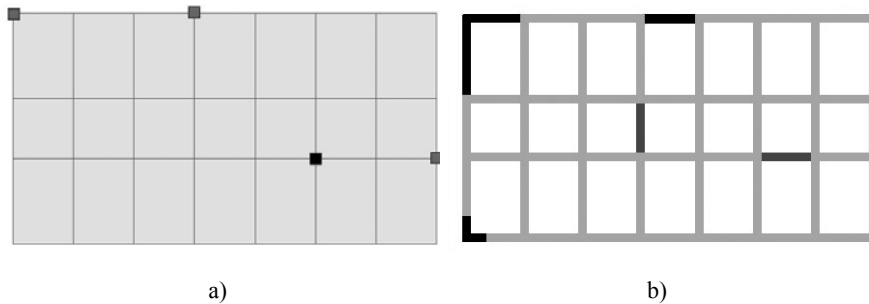


Fig. 3 – Scenarios concerning the position of the removed resistance elements.

The elements considered as initially destroyed are only at the ground floor. Therefore, the case (1) is that of a column close to the middle of the long side; case (2) is that of a column close to the middle of the short side; case (3), a column placed as close as possible to the centre of the structure; case (4), a structural wall parallel to the long side; case (5), a structural wall parallel to the short side. In the calculation models, apart from the initial unique element, it is also eliminated a correspondent surface which is defined, according to the technical regulations, as “local damage”, Fig. 4.

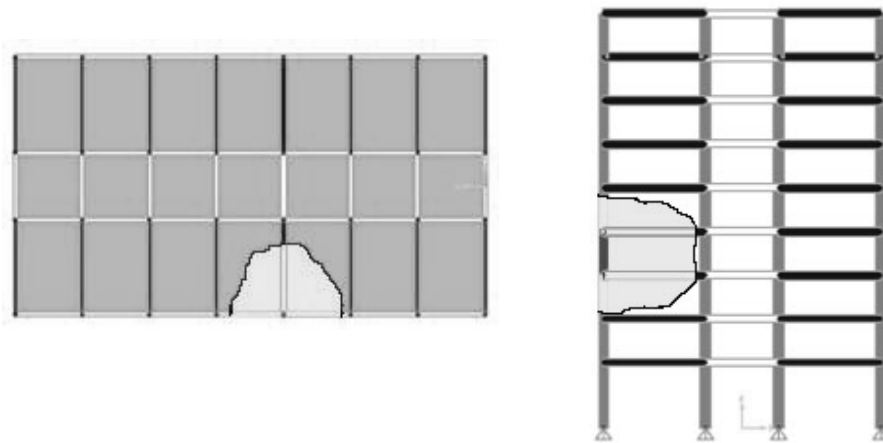


Fig. 4 – The restrictions proposed by the technical regulations for the dimensions of a damage considered local.

For this stage of the research, we have considered the same loadings both for the intact structure and for the structures with missing elements. The results obtained for the cases where some structural elements are supposed missing, are compared to those of the initial situation, where no structural element is missing.

The analyzed data resulted from the FEM program SAP2000-V12.

Case 1. Removal of a pillar close to the middle of the long side

The area above the removed column has an increment of the vertical displacement of 22.86 times (Fig. 5). At the roof level, on the side opposed to that of the removed column, the variation is null, having the same vertical displacement as that at the intact structure.

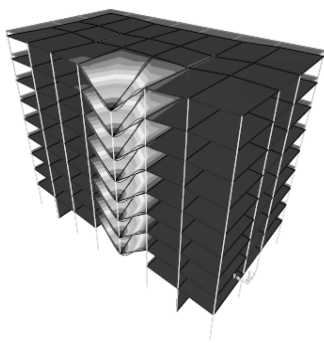


Fig. 5 – Nodal displacement.

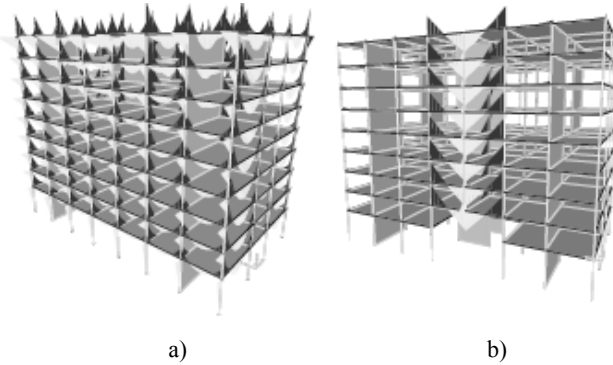


Fig. 6 – Moment diagrams on the transverse axis:
a) the intact model; b) the model with local damages.



Fig. 7 – Axial forces.

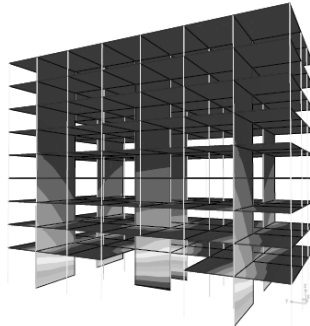


Fig. 8 – Von Mises stresses.

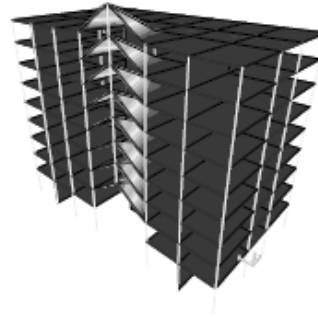


Fig. 9 – Additional vibration mode.

Another obvious change is noted for the bending moment diagram. Even the position of the stretched fibre changes, as it can be observed in Fig. 6. The beams on the two spans flanking the removed column behave as one. The maximum axial

forces maintain their position on the bottom sections of the columns in the middle of the long side (Fig. 7). The maximum value increased with about 27%. For the transversal and longitudinal walls the maximum value of the stress calculated according to the Von Mises criteria increased with about 14% (Fig. 8). It results that, in this case, the additional effect in the walls it's not significant. Regarding the dynamic response, the first three vibration modes do not change. Still, there will appear an additional mode having a period $T = 0.288$ seconds (ranging between the periods $T_4 = 0.303$ seconds and $T_5 = 0.201$ seconds of the intact model) and a vibration mode which is a vertical deformation of the area above the local damage, Fig. 9. The loss of a column and the corresponding area, loads the surrounding area.

When removing a column from the ground floor and the corresponding area as a local degradation from the middle of the long side, the response remains local. It appears an important increment of the nodal displacements in the immediately above the removed columns. Also, the bending moments diagram changes the stretched fibre, something that should be considered when designing the reinforcement. From the dynamic point of view the structure's global behaviour stays unchanged. It appears an additional local vibration mode.

Case 2. Removal of a column near the middle of the short side

When removing a column from the ground floor and the corresponding area of local damages, the structural response remains local. From the dynamic point of view, the vibration modes as well as their succession are similar to the initial situation. A supplementary vibration mode, corresponding to a local vertical vibration, appears.

Case 3. Removal of a pillar from the central area where there are no structural walls

The commentaries that can be made are the same as for the *case 1*.

Case 4. Removal of a wall parallel to the long side

The removal of a ground floor wall parallel to the long side of the structure has a local effect. The local displacement increases 34.28 times; the same type of moment diagram change on the adjacent beams; the appearance of a supplementary vibration mode. The fundamental vibration period increases by 15%.

Case 5. Removal of a wall parallel to the short side

The vertical nodal displacements, immediately above the removed wall, increased 35.29 times. The axial force in the columns from the long side increased in more than 60%. As in all the other cases, the most affected effort is the bending moment. A change in the diagram on two beams placed on both sides of the columns above the removed wall has been observed. Also, the unloading of the rest of the beams has been noted. From the dynamic response point of view it has been observed that: (i) the fundamental mode do not changes its eigenvalue or period; (ii) the second vibration mode, Fig. 10, changes to a torsion one; the rotation is

around a vertical axis that passes through the middle of the external short side opposite to that close to the removed wall; the fundamental period increases with about 24%; (iii) the vibration mode bending type around the longitudinal axis (*i.e.* mode 2 of the intact structure) no longer exists; (iv) mode 4 is the supplementary mode – local vertical vibration.

Removing a structural wall parallel to the short side (from the ground floor) has the same type of local influence presented for the other cases. In the same time removing the wall has a strong impact on the overall dynamic behaviour. Except for the fundamental mode which keeps its shape and period unchanged (as for the intact structure), all the other modes are altered, the transversal vibration disappearing. We consider that this element – the transverse wall – could be considered a key element.

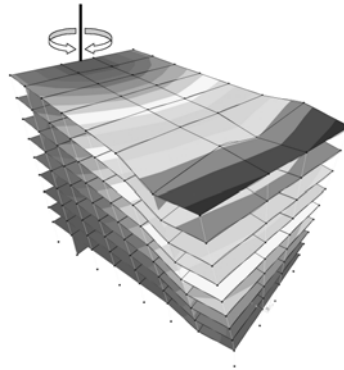


Fig. 10 – Case 5 / mode 2 – torsion.

In Table 1 are systematized the most important commentaries.

Table 1

The systematization of the main commentaries

Case	Commentaries
Entire structure	Basic case
1 – column long side	Local effect, significant increments of the nodal displacements, minor increments of the forces, the first three modes maintain their eigenvectors, a supplementary vibration mode appears in the affected area.
2 – column short side	IDEM
3 – central column	IDEM
4 – wall on the long side	The fundamental vibration period increases by 15%. The force in the remaining wall increases by 36%. The force in the adjacent walls increases by 93%.
5 – wall on the short side	The period for the mode 2 increases by 24%, and the eigenvector changes, now being a torsion vibration. The force in the adjacent wall from the short side increases by 72%. The axial force in the flanking pillars increases by 60%.

4. FINAL COMMENTS

The goal of the study is checking the structure for progressive collapse on the basis of some scenarios proposed by the authors and based on the following hypothesis: apart from the element recommended to be the initial cause of a possible progressive collapse, an additional surface, considered by the codes as local failure, has also been eliminated; the loads are the same for the intact structure as well as for the structures with removed elements.

In this phase of the research some comments can be made:

- The proportion to which the basic shear force is distributed by the frames varies between 10% and 30%; the distribution ratio of the shear force to the structural walls varies between 90% and 70%.
- Removing a column, whatever its position, produces local effects.
 - The vertical displacements of the nodes above the removed columns increase about 23 times. The increments of the forces both in the walls and in the adjacent pillars are not noteworthy.
 - The fundamental eigenvector is the same for all the proposed variants – longitudinal vibration.
- The removal of the walls has both local and global effects
 - The vertical displacements of the nodes above the removed shear walls increase about 35 times. The forces augmentation both in the walls and in the flanking pillars are significant (about 93% in the pillars when the longitudinal wall is removed and about 72% in the walls parallels with the short side when a similar one is removed).
 - Removing a wall parallel with the short side leads to an essential modification of the general dynamic behaviour. The transverse vibration mode disappears and the mode 2 is a torsion one. The increase of the vibration period for the mode 2 is about 24%. We consider that, in this variant of the structural walls positioning, the walls parallels with the short side can be considered the *key element*.

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