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Building Resistance Evaluation to Progressive Collapse by Dynamic Analysis Using Direct Integration Method

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Abstract. In recent decades the issue of progressive collapse has become challenging and necessitated the introduction of the concept "progressive collapse" Brief overview of the analysis methods for structural steel frame to evaluate resistance to progressive collapse is presented. During structural analysis research a series of comparison studies in dynamic and quasi-static analysis was performed. It is observed that dynamic structural analysis to evaluate of frame resistance to progressive collapse is advisable to perform.

INTRODUCTION

Nowadays, the construction of high-rise and large-span buildings and structures with high occupancy is increasingly being implemented. While a possible progressive collapse is considered in the design process, it will be possible to significantly reduce social, environmental and economic losses in the event of natural or man-made emergencies.

A new code of specification 385.1325800.2018 "Protection of buildings and structures from progressive collapse. Design rules. Basic provisions" was introduced on January 6, 2019. This normative document provides for the design of buildings and structures of normal and higher KS-2 and KS-3 consequence classes of various structural systems in order to ensure their protection against progressive collapse.

The new code of specification proposes to use two methods for progressive collapse resistance analysis: quasi-static or dynamic analysis methods.

The aim of the study is to compare analysis methods for progressive collapse resistance in a building.

To achieve this goal, the tasks were defined as follows:

- to develop finite element models for quasi-static and dynamic analysis methods;
- to compare calculation data obtained;
- to perform statistical result processing of two methods.

PROBLEM STATEMENT

Progressive collapse resistance method in a dynamic formulation was carried out in the ANSYS 2019 R1 software using the Transient Dynamic Analysis module. Removing a structural element was modelled using the "Element Birth and Death" ("birth" and deleting an item) command.

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A flat metal multi-level frame was taken as a design model. The element to be removed is the middle column of the first level. Figure 1 shows the general design model.

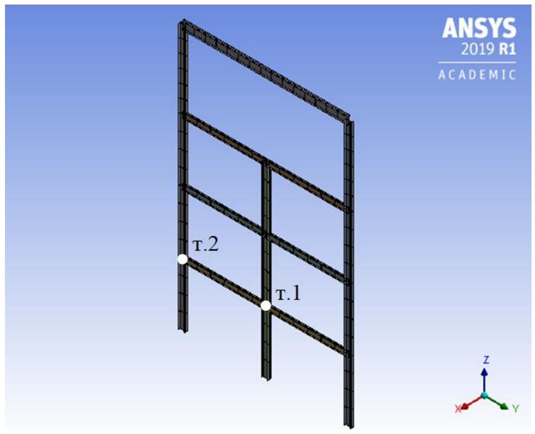

FIGURE 1. General view of the computational frame in ANSYS 2019 R1.

Steel grade of structural elements is C345. The isotropic steel hardening model "Bilinear Isotropic Hardening" is adopted to describe the nonlinear operation of the system elements.

The calculation was made for a special combination of loads with regard to the ratio of normative load duration.

General characteristics of the design model are presented in Table 1.

TABLE 1. General system characteristics.

No.	Characteristic	Value
1	Material density ρ, kg/m^3	7850
2	Elasticity modulus E, H/mm^2	2.06·105
3	Poison's ratio, ν	0.3
4	Yield strength of steel R_{yn}, H/mm^2	305
5	Tangent modulus of elasticity, Pa	10000
6	Integration step	0.005
7	Damping coefficient	0.04

The "Number of Steps" parameter specifies the number of solution steps equal to that of loads. The structural element is "turned off" using the "Element Birth and Death" command at the last step.

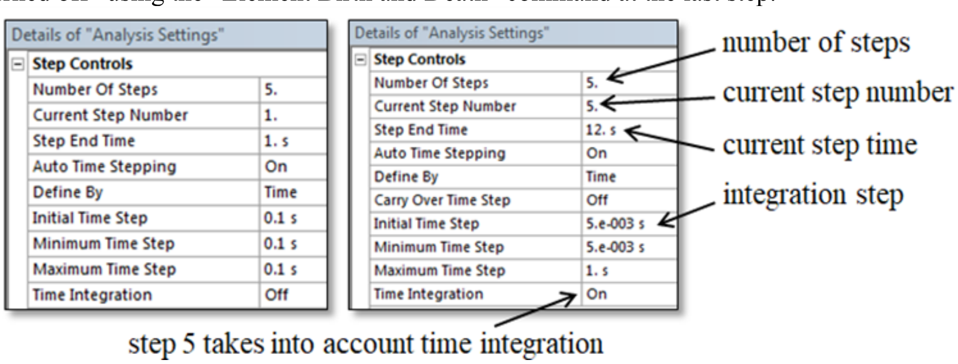

FIGURE 2. Solver settings for dynamic analysis in ANSYS 2019 R1.

Based on the problem analyses in a dynamic formulation with respect to physically and geometrically nonlinear behaviour of a material, structural response in time was obtained until the damping oscillations moment.

For executing a task in a quasi-static formulation, a nonlinear static analysis was considered. According to paragraph 7.2 of the current Code of specification 385.1325800.2018, the calculation was carried out in two stages: at the initial stage all structural elements were included, at the second stage all elements, except for a destructible one, were introduced. The stress-strain state of structures during local destruction was determined together with structural stresses and deformations resulting from normal operation. In addition, the displacement analysis at control points was carried out.

The quasi-static problem was considered in the ANSYS 2019 R1 program in the “Static Structural” static analysis through the “Element Birth and Death” command as well as in the LIRA SOFT software using the “Installation” module.

Instantaneous removal of the column was simulated by the forces determined in this element when calculating according to the primary design model, and applied in the secondary design model with the opposite sign.

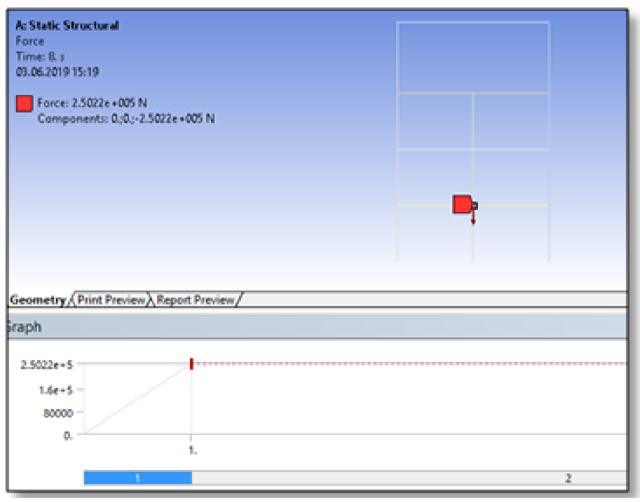

FIGURE 3. Quasi-static formulation. second stage.

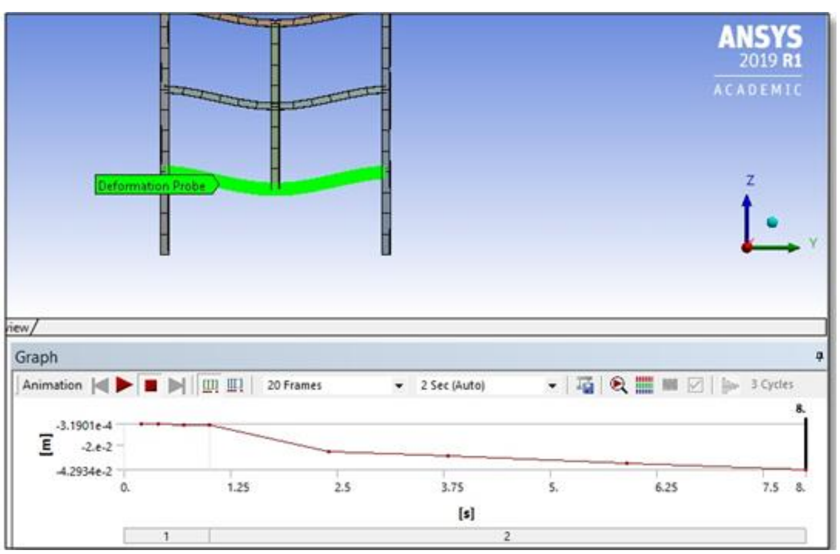

FIGURE 4. Quasi-static formulation. General view of the deformed model.

RESULTS

Displacements and forces at the last stage of load application with a column removed, are calculation data.

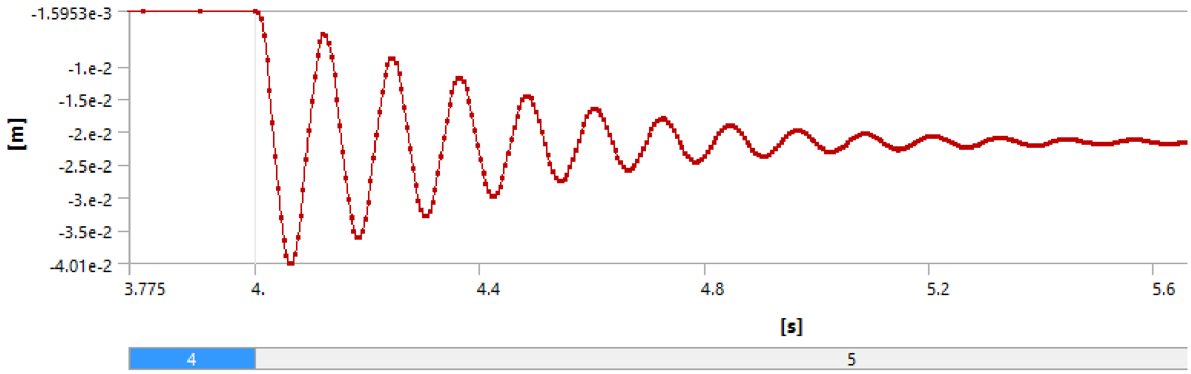

FIGURE 5. Diagram of displacement values at the point of an element destruction in ANSYS 2019 R1 software.

At the yield point of steel, neither structural failure nor plastic deformations were observed. With a view to progressive collapse resistance, the values of the quasi-static method obtained exceeded those of the dynamic method. Calculation data are presented in Table 2.

TABLE 2. Analysis of calculation data of an industrial building in ANSYS 2019 R1 at steel yield strength R_{yn} = 305 N/mm^2

Comparison station	Progressive collapse resistance analysis method					
	Dynamic method		**Quasi-static method**		**Quasi-static method**	
		%		%		%
Maximum displacement along the axis Z in point 1, mm	21.60	100	42.93	198	41.41	192
Maximum longitudinal stress N in point 1, кN	24.88	100	45.72	183	46.90	189
Maximum displacement along the axis Z in point 2, mm	0.57	100	0.83	146	0.98	171
Maximum longitudinal stress N in point 2, kN	-408.3	100	-540.0	132	-550.2	134.8
Maximum deflection moment M in point 2, kN/m	205.33	100	376.5	183	295.63	144

CONCLUSION

In accordance with paragraph 7.6 of the Code of specification 385.1325800.2018, a quasi-static or dynamic method to calculate the resistance of buildings to progressive collapse has to be used. Referring to the results of the set of calculations perfomed, the second method proved to be appropriate. This is evident from the significant difference (as many as 100%) in the results obtained by the dynamic formulation of the problem with those based on the quasi-static method.

It is noteworthy that in some cases the collapse of the system results from the quasi-static method calculation, while the calculation analysis of the dynamic formation provided different results when the calculation was performed and the intensity of plastic deformations was observed.

It should be borne in mind that structural calculations through a dynamic method enable one to assess structural behaviour at any time interval, to detect the destruction moment of a structure and to analyze the corresponding results, thus allowing to avoid further destruction.

Calculations for progressive collapse are required for especially dangerous and technically complex facilities, as their destruction can result in disastrous consequences. Therefore, considering the geometric and physical aspects of the nonlinear behaviour of structures, as well as the dynamic formulation of the problem can be considered rational, despite the complexity and resource intensity of such calculations.

REFERENCES

1. GOST 27751-2014 *Reliability of building structures and foundations. Basic provisions* (Standartinform, Moscow, 2015).
2. Code of design-031-01 *Design standards for earthquake-resistant nuclear power plants* (Gosatomnadzor, of Russia, Moscow, 2001).
3. Code of specification 20.13330.2011 *Loads and impacts. Updated edition od SniP 2.01.07-85* (Minregion of Russia, Moscow, 2010).
4. Code of specification 296.1325800.2017 *Buildings and constructions. Special effects* (Minstroy of Russia, Moscow, 2017).
5. Code of specification 385.1325800.2018 *Protection of buildings and structures from progressive collapse. Design rules. Basic provisions* (Minstroy of Russia, Moscow, 2018).
6. V. Almazov, Construction and reconstruction **6(56)**, pp. 3–10 (2014).
7. D. Gotina and Yu. Tkachenko, New ideas of the new century: materials of the international scientific conference FAD TOGU **2** pp.171–177 (2012).
8. V. Grachev, T. Vershinina and A. Puzatkin, *Disproportionate destruction. Comparison of calculation methods* (Azhur, Ekaterinburg, 2010).
9. D. Drobot, Progressive collapse and survivability of structures (2019), https://dwg.ru/
10. V. Travush, V. Kolchunov and E. Leontiev, Industrial and civil construction **2**, pp. 46–54 (2019).
11. GSA «Alternate path analysis & design guidelines for progressive collapse resistance» (2016).
12. UFC 4-023-03 Unified facilities criteria. Design of buildings to resist progressive collapse (Including Change 3, 2016).
13. ANSYS Release 2019 R1 Documentation, https://ansyshelp.ansys.com