

Estimation of reinforced concrete seismic resistance bearing systems exposed to fire

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Abstract: The article presents the calculation results for a 12-storey reinforced concrete frame building, which is exposed to fire effects. The results of building calculations are given for different combinations of operating and special loads. The analysis shows that the seismic effect during fire impacts changes the building frame's Stress-strain state: it leads to a change in the dynamic strength and deformation characteristics of the bearing elements of the building, bearing elements, and the fire resistance of the structure is reduced. The reinforced concrete frame calculation of a multi-storey building for seismic load showed that the maximum deformation was: along the X axis, 32.852 mm, along the Y axis - 36.762 mm. According to a building analysis for seismic load (9 degrees intensity) simultaneous with fire impacts, the frequencies of the building's natural oscillations increase by 13.8%. Horizontal movements increase by 1.65 times.

1. Introduction

Despite the large number of studies devoted to the operation of reinforced concrete in conditions of high temperatures [1, 2] or the operation of the building frame under dynamic load in normal conditions [3-6], the building or structure operation under conditions of high temperatures and dynamic loads, in the when seismic event is not studied. Nowadays, methodology for calculating the load-bearing capacity of a reinforced concrete frame building that operates under dynamic load under fire conditions has not been developed.

Investigation of building structures seismic resistance under fire impact is one of the priority tasks in the field of construction, as the number of buildings, their responsibility, manufacturability of equipment, etc., is constantly increasing. The problem is the labor input of the experimental analysis [7], which would reflect the full range of information about the deformation of the entire building, operation of certain elements of the bearing structure under the influence of loads special combinations: fire and seismic.

Experimental researches show that high-temperature impacts change the strength and deformation characteristics of reinforced concrete, while the dynamic strength characteristics ones [1, 2] are reduced to a greater extent, therefore, the fire effects for buildings and structures located in seismic regions directly reduce seismic resistance.

High temperature leads to the increase in elasticity modulus of concrete, leading to the increase in natural frequencies.



2. Model setup

For rating the seismic resistance of a multi-storey building frame, subject to firing, the following tasks were set:

1. Non-linear static calculation of a 12-storey frame reinforced concrete building in normal conditions.
2. Calculation of a 12-storey frame reinforced concrete building under a seismic load of 9 points in normal conditions.
3. Non-linearly-static calculation of a 12-storey frame reinforced concrete building in conditions of fire impacts - assessment of fire resistance of load-bearing elements in the time interval of fire impact 0 - 240 min, according to ISO 834.
4. Calculation of a 12-storey frame reinforced concrete building under a seismic load of 9 points under fire impact conditions.

Initial data:

The size of the building in the plan: 24.0x30.0 m.

The height of the building is 74.0 m.

Cross-section of columns: 400.0x400.0 mm.

Cross-section of the beam: 400.0x600.0 mm.

Overlap: 180.0 mm.

After the non-linear static analysis of the building, vertical displacements deformations of the structures were obtained (see Figure 1).

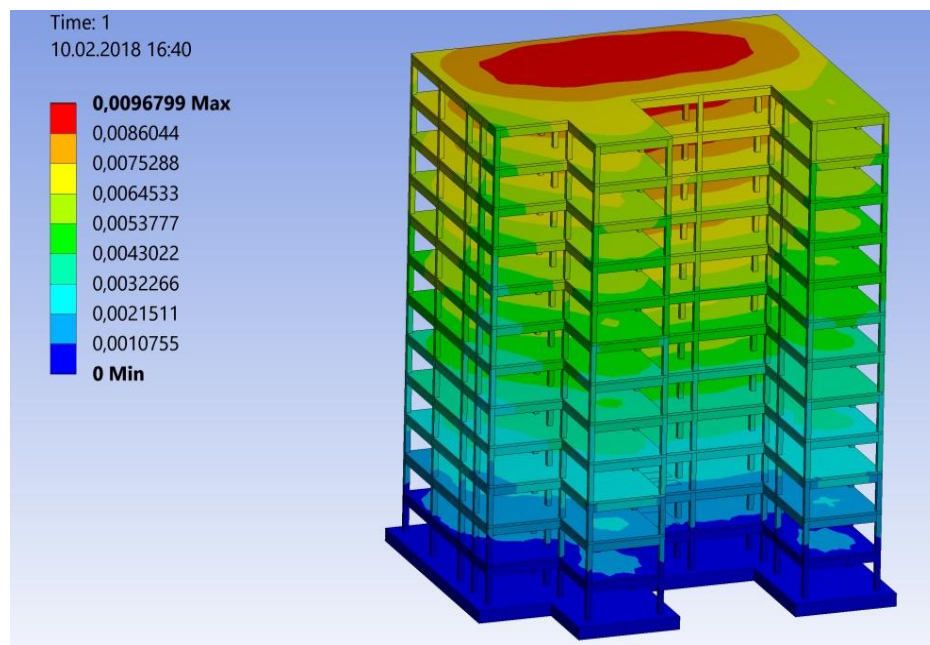


Figure 1. Deformations of building structures in normal conditions.

A nonlinear static calculation of the building frame shows that the maximum deformation is 9.7 mm, which is less than the maximum allowable deflection (30 mm).

The nonlinear static calculation of the building with fire impacts is carried out in accordance with ISO 834, given standard curve for the fire temperature is registered in the software complex ANSYS, assessing the fire resistance of structures up to 4 hours.

According to ISO 834, the temperature of the standard temperature mode is determined by the following logarithmic dependence:

$$T=345\lg(8 \tau +1)+t_e, \quad (1)$$

where T is temperature of environment ($^{\circ}\text{C}$); τ is heating time (min); t_e is the initial temperature, ($^{\circ}\text{C}$).
The graph of temperature versus time is prescribed in ANSYS (see Figure 2).

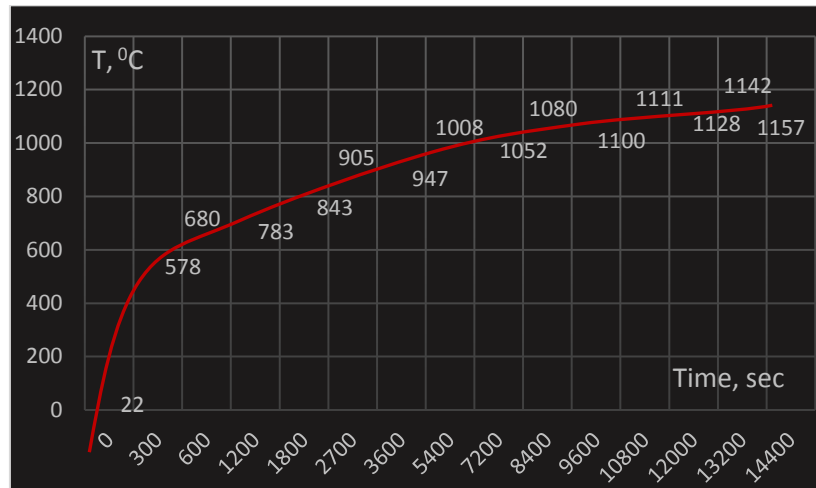


Figure 2. Standard fire temperature curve according to ISO-834.

3. Mathematical model

The fire effect is considered on the 2nd floor of the building. The nonlinear static calculation results of the building during the fire impacts are shown in Figure 3.

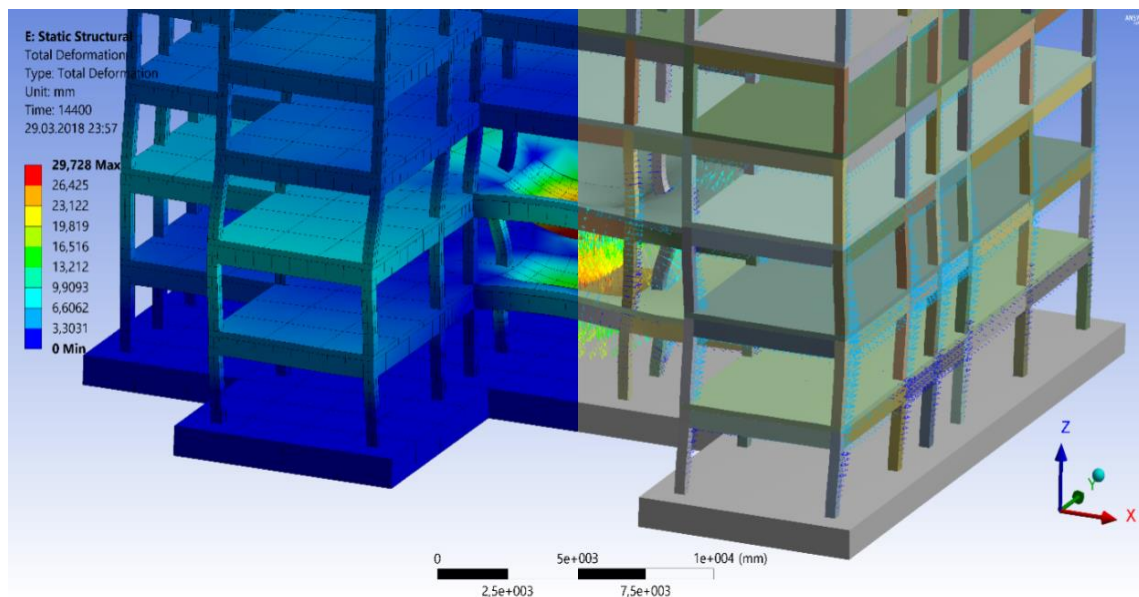


Figure 3. Deformation of building structures in case of fire on the 2nd floor.

The vertical and horizontal deflections of bearing structures calculated in ANSYS are shown in Table 1. Based on the obtained data, it can be seen that the calculated fire resistance for all elements meets the REI fire resistance requirements (FL-123). The fire resistance of the reinforced concrete beam is 245 min, which corresponds to deformations over 30 mm.

For rating the seismic resistance of the building structure [8, 9], the frame of a multi-storey building was analysed for a seismic impact with an intensity of 9 points.

Table 1. Structural deformations under fire impact.

| Structure | REI | Structural deformation, mm | | | | | | Margin of safety % |
|-----------|--------|----------------------------|--------|--------|---------|---------|---------|--------------------|
| | FL-123 | 30 min | 45 min | 90 min | 120 min | 180 min | 240 min | |
| Overlap | 45 | 0.978 | 5.1 | 7.94 | 13 | 19 | 29.5 | 0.3 |
| Beam | 90 | 1.23 | 6.5 | 11.3 | 16 | 23 | 29.728 | Disruption |
| Column | 90 | - | 1.3 | 2.12 | 3.8 | 9.23 | 11.098 | 4 |

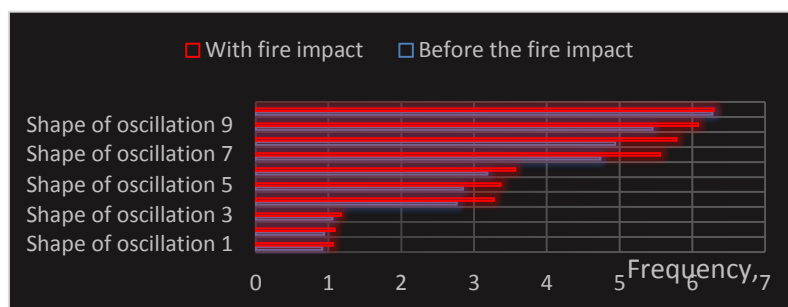
The evaluation criterion of the structures seismic resistance is the deformation of the building in X, Y, Z and the building's oscillations, ensuring the strength and load-bearing capacity of the main load-bearing elements.

The results of natural oscillations' frequency and the corresponding with the main structural elements of the building frame deformation are given in Table 2.

Table 2. Modes of oscillation and displacements of building structures.

| Natural mode | Before the fire impact | | With fire impact | |
|--------------|------------------------|-----------------|------------------|-----------------|
| | Frequency, Hz | Deformation, mm | Frequency, Hz | Deformation, mm |
| 1 | 0.91456 | 0.020484 | 1.0618 | 0.71675 |
| 2 | 0.94195 | 0.019122 | 1.0858 | 0.66022 |
| 3 | 1.0565 | 0.034463 | 1.1683 | 1.1526 |
| 4 | 2.7623 | 0.020695 | 3.2713 | 0.77184 |
| 5 | 2.8445 | 0.01889 | 3.3658 | 0.6838 |
| 6 | 3.1858 | 0.033867 | 3.5662 | 1.1381 |
| 7 | 4.7392 | 0.021345 | 5.5556 | 0.81854 |
| 8 | 4.9403 | 0.01823 | 5.7846 | 0.6456 |
| 9 | 5.4548 | 0.033326 | 6.0794 | 1.1039 |
| 10 | 6.279 | 0.029286 | 6.2957 | 0.92115 |

Comparative analysis' results of natural oscillations' frequency of the building under normal conditions and under fire effects is given in Figure 4.

**Figure 4.** Dependence shape of oscillation before and under fire impacts.

Analysis of the building work under fire exposure shows that the frequency of the building's natural oscillations form increases to 13.74%, this is due to a change in the dynamic strength and deformation properties of materials under fire impacts [10].

The seismic impact on the building is given in accelerogram form.

We set the following parameters of the acceleration amplitude as a function of frequency, calculation response was calculated by a linear-spectral method the calculation the data of the accelerogram are shown in Figure 5.

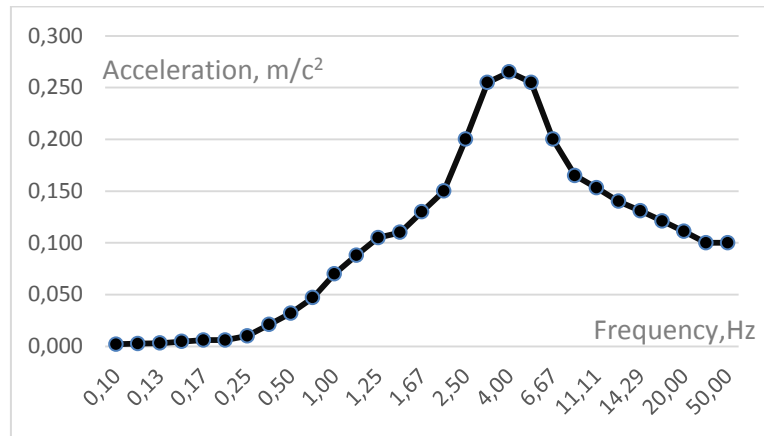


Figure 5. Dependence of acceleration on frequency.

When calculating a building for seismic action under normal conditions, the following results of displacements along the X and Y axes are obtained (see Figure 6).

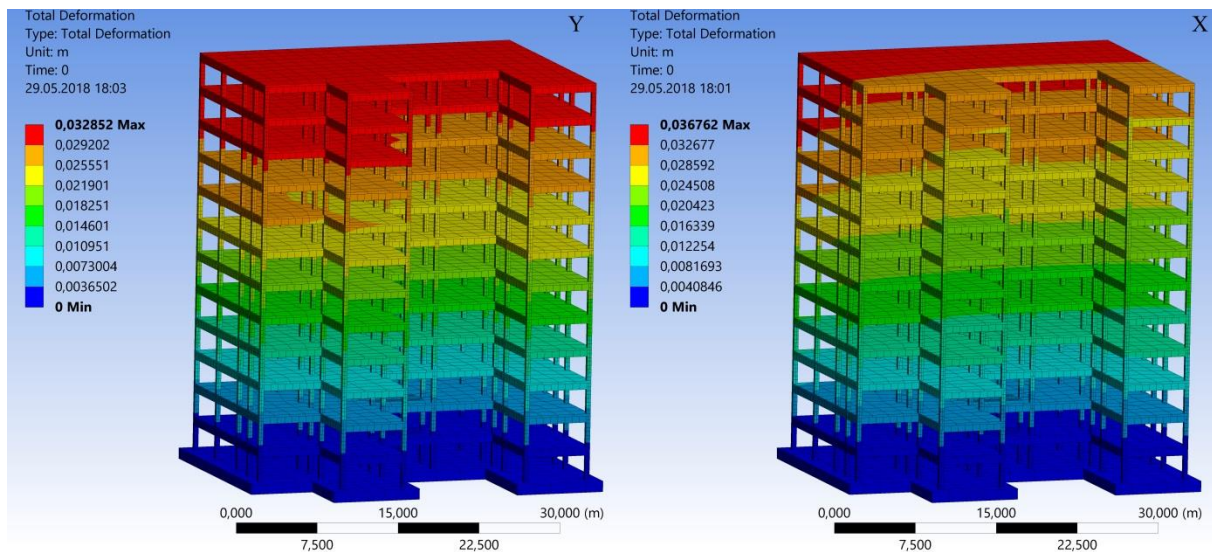


Figure 6. Deformations of the building along the X and Y axes under seismic action.

Calculation of the reinforced concrete frame of a multi-storey building for seismic action showed that the maximum deformation is: along the X axis, 32.852 mm, along the Y axis 36.762 mm.

4. Results

The results of analysis for combined seismic effect with fire impacts:

- Critical deformations of load-bearing structures are achieved after 215 minutes.
- The influence of high temperatures negatively affects to the seismic resistance of the building. The fire effect increases the frequency of vibration modes by 13.74%, which in its turn leads

to a sharp increase in the deformability of load-bearing structures (by 3.5 times), while the dynamic strength characteristics of the building decrease.

- Horizontal movement of the building along the X and Y axes during the fire impact in seismic conditions increased in 165%. The fire resistance of the frame elements does not meet the fire resistance requirements for R.

5. Conclusion

The seismic response of reinforced concrete buildings under conditions and after the fire impact significantly changes. Taking into account the influence of fire impact allows to improving the forecast quality of reinforced concrete structures Stress-strain state in earthquakes.

References

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