



FIRE RESISTANCE OF WALL PANEL SUBJECTED TO SEISMIC LOADING

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ABSTRACT

Research of the wall panel was carried out after seismic loading test of experimental fragment. It was included assessment of deflected mode and temperature distribution for the wall panel during the fire test. Fire resistance class of wall panel for the integrity and insulation criteria was determined in consequence of the fire test. Fire resistance class of wall panel for the load bearing criterion was determined in consequence of analysis and fire test.

INTRODUCTION

Earthquakes often cause natural disasters (landslides, tsunamis, etc.), the results of which are much more tragic. Fire is one of these phenomena. Fire accidents after earthquakes viz. 1906 San Francisco, 1923 Tokyo and 1999 Izmit are among the most famous examples (Chen and Scawthorn, 2003).

Gas leaks due to pipe or gas appliance failure, electrical distribution system problems, flammable materials spills etc are main causes of ignitions after an earthquake (Mohammadi et al., 1992). Post-earthquake fires were spread because of tardy late detection and reaction dependent of communication facility damage, traffic queues, water supply breakdown due to pipe failure etc. Consequences of post-earthquake fires analysis has exposed limitations of earthquake-resistant building and cases of violation of fire safety rules such as short fire breaks between buildings, combustible building materials, deficient fire resistance of building constructions etc. Post-earthquake fires may cause greater damages to buildings than earthquake. Information about various post-earthquake fires tabulated thereunder in Table.1 (Chen and Scawthorn, 2003).

Table 1. Consequences of post-earthquake fires

Earthquake	Magnitude	Causes of fire	Outbreaks of fire	Causes of fire spread	Number of collapsed buildings	Number of perished
1906 San Francisco	8,3	Gas leaks due to pipes or gas appliance failure	52	Water supplies breakdown	Over 28000	Over 3000
1923 Tokyo	7,9	Cooking on charcoal braziers	227	Adverse meteorological conditions, dense urban aggregation of wooden buildings	447000	About 140000
1995 Kobe	6,9	Electrical faults, gas leaks	237	Water supplies breakdown	About 7000	6434

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SEISMIC LOADING TEST OF EXPERIMENTAL FRAGMENT

Experimental single-storey fragment of nine-storey building was designed and fabricated for the purpose of strength, stiffness and cracking resistance assessment of large-panel buildings under the action of the static equivalent of seismic load intensity 7 to 9 points.

Wall panels with embrasures were typical structural elements of the fragment. External wall with window aperture was a reinforced-concrete sandwich panel 265 mm thick with middle lagging layer. Interior walls with door aperture and blind wall were reinforced-concrete single-layered panels 200 mm thick. Anchoring loops of wall panels' joints were special features of building structure. Wall panels were fixed to the floor with the use of concrete blocks by anchor studs. Four hollow core slabs 220 mm thick served as roof of experimental fragment.

Seismic loading tests of the fragment were performed under the simultaneous action of vertical static load and lateral variable action imposed using hydraulic jacks with automatic pumping stations and simulated the seismic load intensity 7 to 9 points (see Fig.1). Due to imposed action, constructions of experimental fragment were sustained such damages as diagonal cracks in upper corners of the embrasures of wall panels, cracks along the anchor canals etc. Experimental fragment was dismantled after tests.



Figure 1. Loaded experimental fragment

FIRE TEST OF WALL PANEL

Internal load-bearing blind wall panel BC-111 measuring 3040mm (H) × 3160mm (W) × 200mm (D) had been chosen among the constructions of experimental fragment for the fire test. Strength class for concrete of the wall panel was C16/20. Wall panel had double wire-mesh reinforcement. Required fire resistance of the wall panel was REI 120. Vertical crack had grown from the anchor canal across the wall panel in consequence of seismic loading tests. Width of crack was over the 0.3 mm to 0.45 mm range (see Fig. 2). The choice of this panel was justified as a test specimen shouldn't be made of different types of materials (e.g. block or bricks) except it reproduced real construction (Ukrainian Standard, 2007).

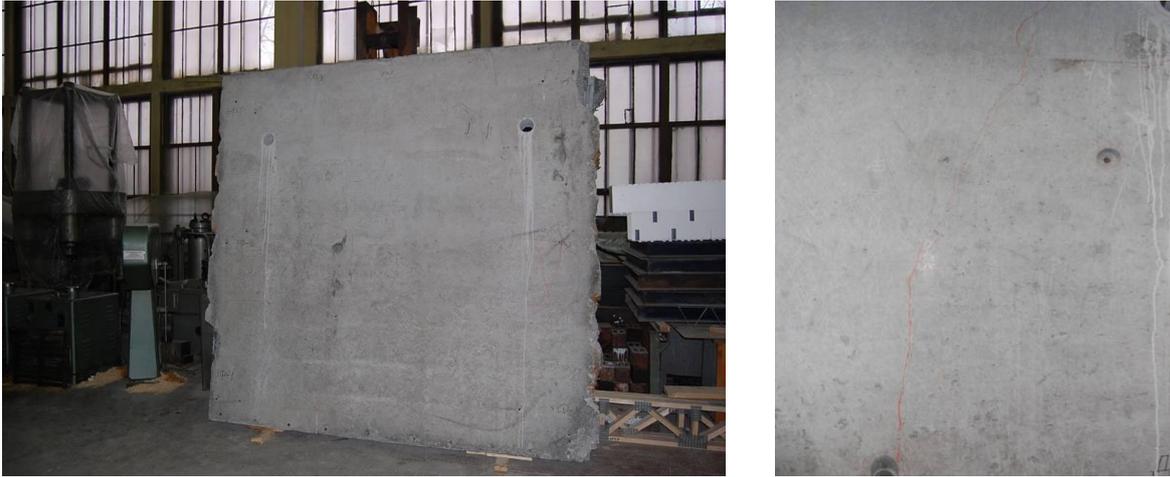


Figure 2. Wall panel BC-111 and vertical crack across the wall panel due to seismic loading test

Fire test of the wall panel was carried out according to standard temperature-time curve without the load application in compliance with requirements of Ukrainian Standards DSTU B V.1.1-4:98* and DSTU B V.1.1-19:2007 harmonized with European Standards EN 1363-1:1999 and EN 1365-1:1999 respectively.

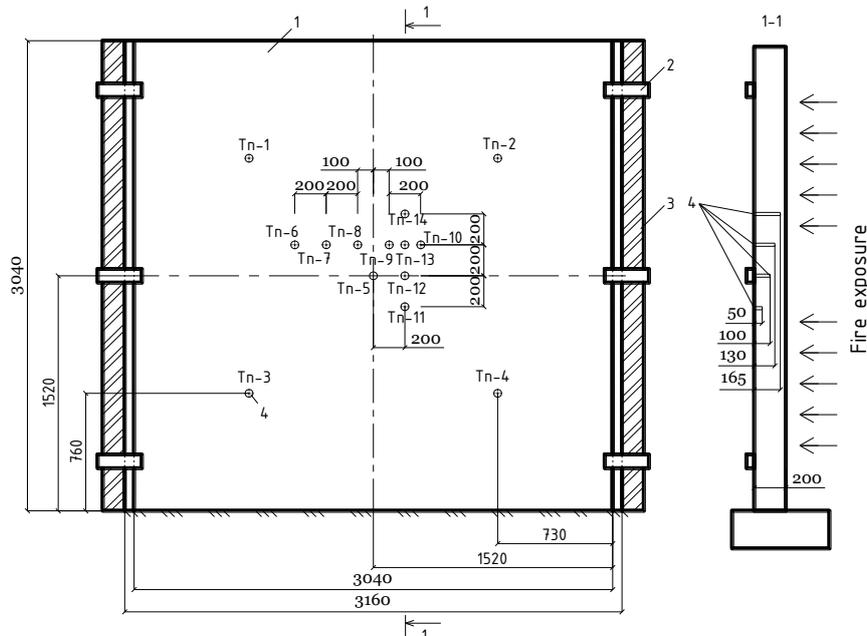
Vertical fire resistance test furnace had an internal chamber measuring 3000 mm (W) x 3000 mm (H) x 1500 mm (D) where six flame burners placed. Furnace provided fire exposure on the one side of wall panel. The average temperature in the furnace T_f grown during the fire test according to the standard fire curve defined as Eq.(1):

$$T_f = 345 \lg(8t+1) + 20, \quad (1)$$

where t – duration of fire exposure, min;

T_f – temperature corresponded to time t , °C.

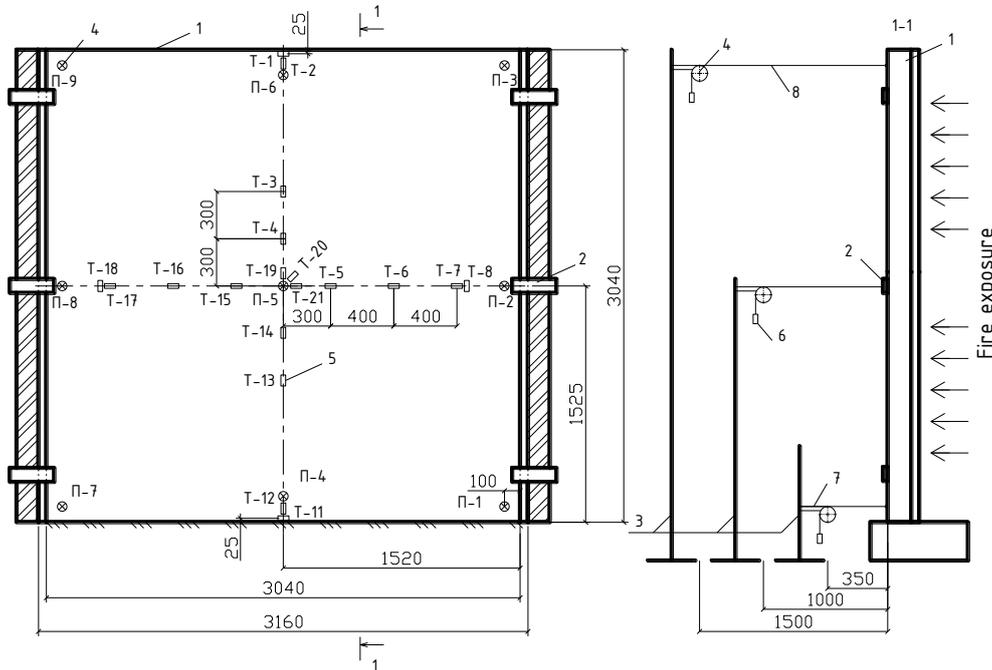
Temperature of the wall panel was taken by thermocouples situated on the non-exposed surface, through the wall panel cross-section, on the reinforcement near the exposed surface (see Fig.3).



1 – test specimen of the wall panel BC-111; 2 – fixtures; 3 – fire resistance test furnace; 4 – thermocouples: Tn-1 – Tn-5 – situated on the non-exposed surface; Tn-6 – Tn-10 – situated on the reinforcement near the exposed surface; Tn-11 – Tn-14 – situated through the wall panel cross-section

Figure 3. Layout of thermocouples

Horizontal displacements of the wall panel were measured by remote deflectometers on some tripods that are placed at a distance to test specimen during the fire test. Fiber strains of non-exposed surface were measured by nineteen resistive-strain sensors situated at thirteen points on the non-exposed surface: in the center, along the horizontal and vertical axes of symmetry (see Fig.4).



1 – test specimen of the wall panel BC-111; 2 – fixtures; 3 – tripods; 4 – deflectometers; 5 – resistive-strain sensors; 6 – plumbs; 7 – clamps for mounting of deflectometers; 8 – wire

Figure 4. Layout of deflectometers and resistive-strain sensors

Fire test of the wall panel began when flame burners in the furnace turned on. Temperatures in the furnace, on the non-exposed surface, through the wall panel cross-section, on the reinforcement near the exposed surface were taken every minute, displacement and strains were measured every five minutes.

Diagrams of temperature are shown in Fig.5 and Fig.6. The horizontal part of the diagrams indicated the intensive evaporation of moisture at 100 °C. It prevented wall panel warm up to higher temperatures. The average temperature rise was 38 °C over the whole of the non-exposed surface. The maximum temperature rise at any point of that surface was 43 °C. These values didn't exceed 140 °C and 180 °C respectively (Ukrainian Standard, 1998).

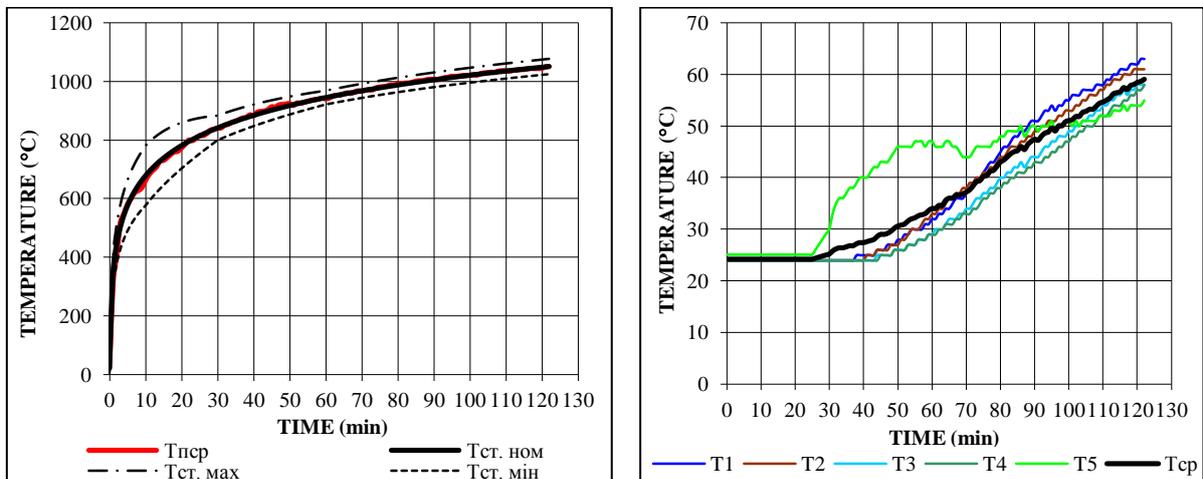


Figure 5. Diagrams of temperature in the furnace and on the non-exposed surface of the wall panel

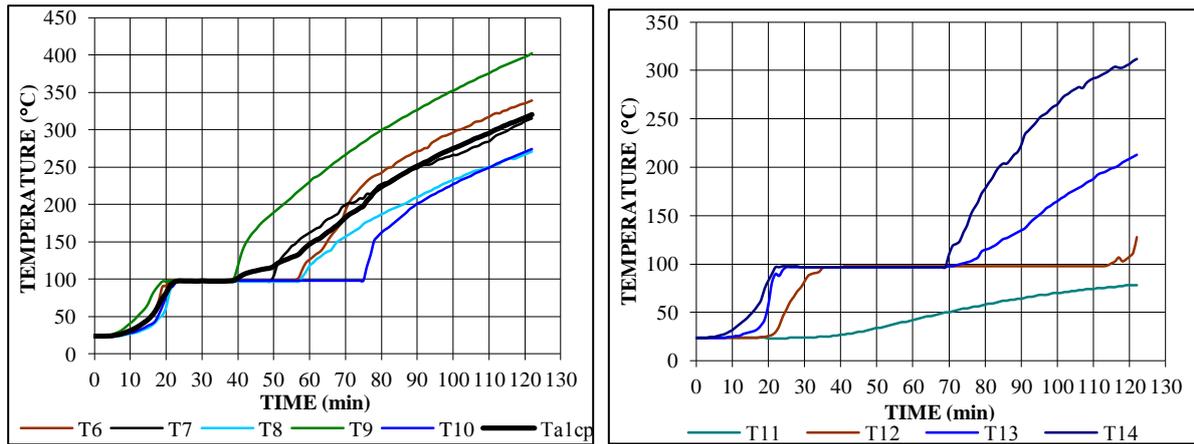


Figure 6. Diagrams of temperature on the reinforcement near the exposed surface and through the wall panel cross-section

The wall panel flexed toward the fire exposure. While the middle of the panel moved aside exposure 44 mm and panel angles deviated away from the furnace about 20 mm. Diagrams of displacements and fiber strains are shown in Fig.7.

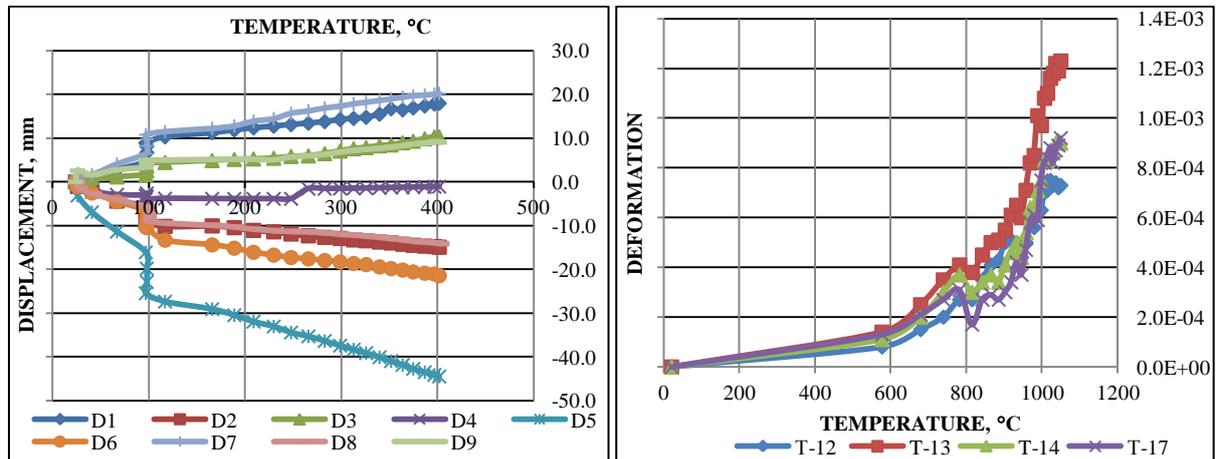


Figure 7. Diagrams of displacements of the wall panel and fiber strains of non-exposed surface

Such characteristic changes of the wall panel were noted by means of the visual, photo and video observation during the fire test (see Fig.8):

- at the non-exposed surface was seen exudation of moisture at first from the cracks along the anchor channel, then – in all holes and cracks after the 20th minute;
- angles and upper bound of the test specimen deviated away from the furnace, central area of the specimen bend aside fire exposure from the 40th minute until the end of the fire test;
- intensive non-exposed surface evaporation of moisture began after 75 minutes.

Cracks existent prior to the fire test were clearly visible on the surface of the test specimen after complete evaporation of moisture. The concrete layer of exposed surface became fragile. It was covered with a mesh of micro-cracks. Concrete cover to reinforcement of exposed surface wasn't damaged. Spalling of concrete cover to the reinforcement of exposed surface of the wall panel didn't occurred.



Figure 8. Wall panel BC-111 during the fire test

The fire test had been continuing for 122 minutes. Integrity and insulation failure (criteria E and I) of wall panel BC-111 didn't occurred after the test for fire exposure according to the standard temperature-time curve for a period of time duration of 122 minutes. Thus, the fire resistance period of the wall panel was 122 minutes for the integrity (E) and insulation (I) criteria.

Wall panel BC-111 was tested for axial compression after fire test. Axial compression test was stopped after loading of $P = 120$ tons because of partial damage of the upper corner of the test specimen.

Three cylindrical specimens with a diameter of 94 mm and a height of 97, 128 and 138 mm were tested for axial compression for determination of compressive strength of concrete. Compressive strength reduction of concrete was 17.2 % prior to seismic loading test and after the fire test.

CALCULATED&EXPERIMENTAL ANALYSIS

Calculated&experimental approach was applied for determining of load-bearing capacity (criterion R) for the fire exposure according to the standard temperature-time curve for a specified load combination and for a period of time duration of 122 minutes. This approach combined advanced calculation methods of stress-strain state of constructions and fire test results such as temperature over the non-exposed surface, temperature distribution through the wall panel cross-section (see Fig.9), reinforcement temperature near the exposed surface, etc.

Advanced calculation methods included calculation models for the determination of (European Standard, 2004):

- the development and distribution of the temperature within structural members (thermal response model);

- the mechanical behaviour of the structure or of any part of it (mechanical response model).

The thermal response model included the consideration of the temperature dependent thermal properties of the materials (European Standard, 2004).

The mechanical response model took into account the changes of mechanical properties with temperature (European Standard, 2004).

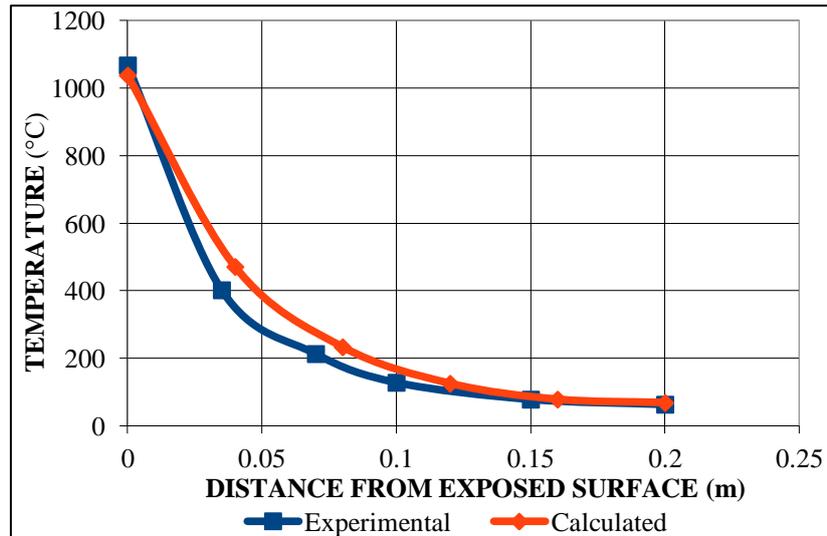


Figure 9. Temperature distribution through the wall panel cross-section

Analysis was performed using FEM based software: Ansys and Lira. Wall panel was approximated by physically nonlinear arbitrary 3D (8-node) isoparametric solids, for which exponential stress-strain relationship of materials realized. FE model of wall panel had hinged lower side. The vertical edges of the model were freely supported. Uniformly distributed load value of $1.86 \times 10^3 \text{ kN/m}^2$ was applied on the upper side of the model. Effects of fire action were realized by means of strength and deformation properties reduction and thermal elongation of concrete and of reinforcing steel depending on temperature distribution through the wall panel cross-section received from the fire test.

Stress-strain state of the wall panel BC-111 was determined by the results of calculation reproduced the behavior of construction during the fire test (see Fig.10). The wall panel flexed toward the fire exposure due to combined action of static load and fire exposure on the one side. Middle of the panel moved aside exposure and panel angles deviated away from the fire.

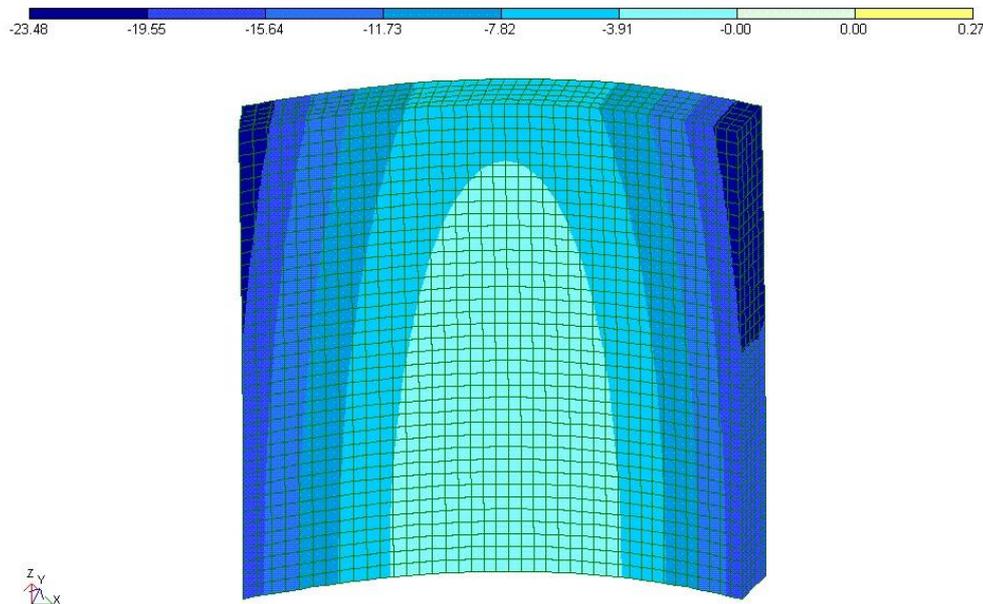


Figure 10. Deflected mode and displacements (mm) of the wall panel

As a result of analysis loss of load-bearing capacity (criterion R) of wall panel BC-111 didn't occurred for the uniformly distributed load and fire exposure according to the standard temperature-time curve duration of 122 minutes. Therefore, required fire resistance REI 120 satisfied for the wall panel with seismic damages.

CONCLUSIONS

Integrity and insulation failure (criteria E and I) of wall panel BC-111 didn't occurred after the test for fire exposure according to the standard temperature-time curve for a period of time duration of 122 minutes.

Compressive strength reduction of concrete was 17.2 % prior to seismic loading test and after fire test.

As a result of analysis loss of load-bearing capacity (criterion R) of wall panel BC-111 didn't occurred for the uniformly distributed load and fire exposure according to the standard temperature-time curve duration of 122 minutes. Therefore, required fire resistance REI 120 satisfied for the wall panel with seismic damages.

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