Nonbearing Wall infill Under Seismic Impacts In Terms Of Non-Linear Static Analysis

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Abstract. The presence of wall infill during seismic impacts is one of the key factors that significantly affect the seismic stability of buildings. Also, irregularity of configuration in plan and height can often lead to more serious damage comparing to regular buildings, due to torsional oscillations and stress concentration on individual elements. The purpose of this article is to study the behavior of various irregularities in the shape of buildings under seismic impacts in terms of non-linear static analysis, taking into account the non-bearing wall infill. For this purpose, five typical geometric shapes of the building plan used in Ukraine and abroad (rectangular, + shape, L-shaped, T-shaped and 4-shaped) were adopted. The calculations were performed using the Pushover Analysis (nonlinear static analysis) method in CAD Lira-SAPR 2019. The main parameter that forms the basis for seismic stability analysis is the story drift under seismic impacts. Obtained results indicate the need to take into account the effect of wall infill, as this can lead to an increase in the seismic stability of the building and stress concentration on individual elements, which can lead to their collapse.

1. Introduction
Ensuring the reliability and safety of construction in seismic areas is a complex engineering challenge. Modern design norms [1-2] require consideration of the behavior of structural material beyond elasticity. Within the existing systems of assessment of actual seismic stability, used in seismic regions of different states, normative documents regulate the consideration of such factor as “influence of irregularity” [3]. There are two types of structural irregularity; vertical irregularity (also called height irregularity) and irregularity in plan (also called plan asymmetry). Vertical irregularity usually refers to the uneven distribution of mass over the height of a multi-story structure or geometric displacements that change story plan between adjacent stories. Plan irregularity is usually considered as irregular distribution of rigidity or masses in a plan, which results in a torsional reaction of the structure when it is exposed to seismic excitation. Buildings with plane irregularity quite often receive serious damage during earthquake, since response of the structure is not only transverse but also torsional. According to American FEMA-154 [4], the degree of irregularity in the plan is up to 92% (in maximum area for highly seismic zones). According to Swiss system [5] the irregularity is equal up to 100% (both in the zone of the minimum and maximum area), and according to New Zealand system [6-7], this parameter also varies within fairly wide limits.

1.1 Analysis of recent studies
International building code experience is very contradictory when considering the influence of non-bearing wall infill, the consequences of earthquakes are considered as decisive argument. According to the results of their analysis, the influence of non-bearing wall infill on the seismic stability of frame buildings was identified and systematized [8] with taking into consideration the nonlinear behavior of reinforced concrete and requirements the second group of limit states [9].

1.2 Purpose of the work
The purpose of the work is to study the behavior of various irregularities of the configuration of buildings under seismic impacts, taking into account the non-bearing wall infill. This work focuses on buildings with flat slab frame.

2. Main part
This numerical study is the final third stage of the study. The first stage of the study consisted of full-scale testing of multi-story buildings with non-bearing wall infill. The second stage is laboratory studies of wall infill fragments on horizontal
shear effects.

The first stage. Number of full-scale and experimental tests was conducted in order to obtain reliable information about behavior of structures with irregular shape in plane considering non-bearing wall infill under earthquakes and vibrations. The tests were performed in three stages: June 15, 2015, August 5, 2015, and August 31, 2015 in the course of in-situ concreting, construction of nonbearing wall infill and obtaining of access to the facility, taking into account the possibility of using a crane to strike the building with wrecking ball attached to hook (tests were conducted with the participation of Murashko A.V., Mikhailova A.A., Mikhailova N.A.). Oscillations were excited also due to strikes by a tamper (Peri formwork beam) and recording of oscillations from wind effects (Fig. 1).

Strikes with wrecking ball stroke central loading core of a building at the level of cover and on the reinforced concrete parapet wall at the level of the second floor. Tampers were also used to strike central loading core at different altitudes (Fig. 2).

Obtained results proved that the method for excitation of oscillation affects only oscillation amplitude while values of oscillation periods remain unchanged. The obtained value of the oscillation periods is 1.63 sec. was compared with the numerical model -1.6556 sec. The second translational and third torsional mode of their self-oscillations could not be excited.

The second stage. Experimental tests were carried out in the laboratory of the Department of Reinforced Concrete and Transport Structures of the Odessa State Academy of Civil Engineering and Architecture. Four identical fragments with dimensions 1200x1200x100 mm were prepared (Fig. 3).

Fragments of the masonry were tested on a special stand under a monotonous incremental loading (0.4 kN and then to the destructive load - Psection = 4 kN. The tests include the following steps:

- Horizontal concentrated static load is applied in steps of 10% of the destructive load at the level of the upper part of the frame/
- Horizontal low-cycle focused alternating load (fig.4), increased by 10% of the destructive load at the level of upper part of frame (1st stage 10% left, 2nd stage 10% right, 3rd stage 20% left, 4th stage 20% right).

Upon testing of fragments, the displacement of the upper area of the frame in the plane of horizontal seismic loads and the relative displacements along the diagonals of panel were measured.

Figure 1. Object of field studies, a) - Photo fixation of building

Figure 2: Tamper strikes in the elevator section

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Analyzing the result of the experimental tests, we see that the fragments perceive horizontal forces up to 4 tons under deformations up to 13 mm.

Figure 4. Diagram of load/deformation at horizontal low-cycle concentrated alternating load

The third stage is numerical simulation based on conventional idea of building behavior in an earthquake: all wall infill were modeled by loads considering non-bearing wall infill in explicit form.

For calculations, buildings with dimensions 36x36 m² are used, bays are multiple of 6 meters. The structural scheme of buildings: girdless framework structure from reinforced concrete. Story height is 3 m. Building has 4 stories. Columns are square with the size in the section 400x400 mm. Working reinforcement has diameter 20 class A500C. Floor slabs are made of monolithic reinforced concrete, reinforcement has diameter of class A500C (Fig. 5). When modeling and calculating 5 models in LIRA-SAPR, 2 types of calculations were performed: Linear spectral and Non-linear (Pushover).

Pushover Analysis allows identification of errors that can be made in the design process. At this stage, the calculation results can be divided into 2 stages. In the first stage, the percentage of the seven-point seismic impact that results in maximum story drift (collapse prevention level) was analyzed, and in the second stage, the percentage of the seven-point seismic impact that result in dimensional instability of the system (progressive collapse) was analyzed.

Results. Numerical modeling for buildings of various shapes disregarding non-bearing wall infill provided similar results: 50% of the seven-seismic impact. The simulation results for the same shapes in the plan, considering non-bearing wall infill, showed results that significantly change depending on the shape in the plan (the results are shown in Fig. 6 and Table 1).

Shapes F4 and F-5 r showed greatest increase in seismic stability, and shapes F-6 showed the smallest increase in seismic stability.
4. Upon designing buildings and structures, it is necessary to take into account the effect of non-bearing wall infill by performing duplicate calculations.

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1. The results of previous field and laboratory experiments have been confirmed by the numerical modeling described in this study.

2. Non-bearing wall infill has a significant influence on drift value: the increase in area of maximum drift was within the range from 10% to 32%.

3. Consideration of non-bearing wall infill results in redistribution of seismic impacts on columns in the central part of the building.

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**Table 1**

| Shape | Part of the seismic impact perceived by the building at 7 points, [%] |
|-------|------------------------------------------------------------------|
|       | Without non-bearing wall infill | With non-bearing wall infill | Exceeding of maximum drift | Complete destruction |
| F-0   | 50 | 61 | 91 | |
| F-3   | 50 | 57 | 57 | |
| F-4   | 50 | 64 | 94 | |
| F-5   | 50 | 66 | 70 | |
| F-6   | 50 | 55 | 56 | |

**Figure 6.** View of the design model of the building during destruction, with non-bearing wall infill (top) and without it (down).