Study of the vibration influence on load-bearing floor structures in case of machinery operation

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Abstract. In this article, the impact of vibration loads on load-bearing floor structures is investigated. These loads were caused by machinery operation process in the five-storey factory building. Within this case study, examination of the structure was performed to measure the real vibration level and evaluate the damages to the structure. The analysis of the results has shown overloading the structures by machinery vibrations. The paper reflects a reasonable approach to rapid estimating of amplitude limits for floor structures avoiding complex calculations. Measured experimental values of amplitudes and precipitations under various productivity levels are given in this study. Theoretical and experimental data comparison appeared slabs subjected to vibration overloading and dynamic deflections. Some control points have shown significant exceeding amplitude limitations. Provided investigations of structure damages, in this case, also confirmed critical areas. It was revealed that incorrect machinery service entailed excessive vibration loads on the structures. Subsequent reinforcement works were provided to eliminate the cracks in structures.

1. Introduction

Among all mechanical impacts on buildings and structures vibration is the most hazardous. Fluctuations caused by vibration lead cracks occurring and subsequent destruction of a building structure. This paper describes a real engineering case emphasizing the importance of vibrations accounting during the whole life cycle of the structure. The studied case appeared after the request addressed to the authors from a pharmaceutical company for scientific and technical supervising of a project. The milestone of that project was simultaneous cracks appearing (Figure 1 and Figure 2) on the floor structures located under the production department.

Figure 1. Structures before cracks appearing.

Figure 2. Structures after cracks appearing.
It was investigated that cracks had developed after new product line launching in a frame of factory modernization. Therefore, it was supposed to run according to a common approach: to classify [1, 2] the vibration source, to collect necessary data [3] and to perform further vibration control [4].

2. Study Background
The factory building is developed as industrial five-story frame constructed with precast reinforced concrete (RC) structures. Column span is 6 meters in the longitudinal and transversal direction. Cross-section of RC columns varies depending on the floor (600x400 mm on the first two floors and 400x400 mm on the next floors). Beams and columns connections are assumed to be rigid. Precast RC floor ribbed slabs (6000x1500x400 mm) are supported by T-shape (RC) beams (6000x800x650 mm). The section of building is given in Figure 3.

![Figure 3](image3.png)

**Figure 3.** Section of factory building: 1-5 – damaged floor covering layers; 6 – machinery (tablet press); 7-8 – damaged RC ribbed slabs.

![Figure 4](image4.png)

**Figure 4.** Tablet press.

![Figure 5](image5.png)

**Figure 5.** Control points position.
The machinery (tablet press KILIAN S250 [5]) was allocated on the fourth floor. It was purchased by the company to produce nutritional supplements in the tablet form. The press appearance is shown in Figure 4.

In aim to investigate the current vibration parameters during machinery operating special control points were positioned on the fourth floor and field vibration test was performed. The amplitude and precipitation were measured with vibrometer VM-6380 [6].

3. Results and Discussions
The basic indexes of the press machinery which affect the level of vibrating loads are: a production capacity level, a moulding pressure and a tablet diameter. Therefore, vibration loads on floor structures were tested under different machinery operating modes. Obtained experimental data are shown in Tables 1-3.

Table 1 indicates the results of amplitude and precipitation measurements on floor structures for press productivity 80 000-110 000 tablets per hour under a moulding pressure 30-35 kN while producing a large (11 mm in diameter) flat tablet (assumed as mode 1).

| Productivity, tablets/hour | Point position | Amplitude, mm | Precipitation, m/s² |
|----------------------------|----------------|---------------|---------------------|
| 80000                      | under the press | 0.025         | 0.15                |
| 80000                      | at 2 m. distance | 0.025         | 0.13                |
| 85000                      | under the press | 0.03          | 0.17                |
| 85000                      | at 2 m. distance | 0.03          | 0.16-0.19           |
| 90000                      | under the press | 0.05          | 0.13-0.25           |
| 90000                      | at 2 m. distance | 0.03          | 0.14-0.20           |
| 100000                     | under the press | 0.04          | 0.24-0.31           |
| 100000                     | at 2 m. distance | 0.02          | 0.16-0.22           |
| 105000                     | under the press | 0.05-0.06     | 0.19                |
| 105000                     | at 2 m. distance | 0.02          | 0.09                |
| 110000                     | under the press | 0.06          | 0.23-0.29           |
| 110000                     | at 2 m. distance | 0.015         | 0.15                |

Table 2 shows the results of measurements on floor structures for press productivity 130 000 tablets per hour under moulding pressure 32 kN while producing a small (6 mm in diameter) flat tablet (assumed as mode 2).

| Productivity, tablets/hour | Point position | Amplitude, mm | Precipitation, m/s² |
|----------------------------|----------------|---------------|---------------------|
| 130000                     | under the press | 0.01          | 0.11                |
| 130000                     | at 2 m. distance | 0.006         | 0.11                |

Table 3 demonstrates the results of measurements on floor structures for press productivity 130 000 tablets per hour under a moulding pressure 18 kN while producing a small (6 mm in diameter) flat tablet (assumed as mode 3).

| Productivity, tablets/hour | Point position | Amplitude, mm | Precipitation, m/s² |
|----------------------------|----------------|---------------|---------------------|
| 130000                     | under the press | 0.01          | 0.09                |
| 130000                     | at 2 m. distance | 0.005         | 0.10                |

Due to national standards vibration loads are limited by technological or medical [7] requirements. But in this case we deal with structural damages, therefore further we will focus on that aspect. Industry
buildings could be subjected to dynamic deflections caused by operating machinery equipment inside. As a rule, medical regulations are the strictest and often it’s not necessary to account the effect of dynamic deflection. Thought it shows significant influence when low-level medical demands are required (e.g. limited human access) or sensitive to vibration structures are used (e.g. long-span multi-storey frames). In late 80-s values for structure’s amplitude regarding limited dynamic deflection were presented. This simplified methodology [8] is based on a relatively conservative approach, but it helps to avoid complex calculations [9]. Dependences between limit structure’s amplitude and machinery frequency according to the mentioned method are given in Table 4. The operating pressing frequency of tablet machinery varies in range (22-36) Hz for productivity from 80000 to 130000 items/hour respectively. Using data from Table 4, the limited structure amplitude can be defined for that range of frequencies. Comprehensive chart with experimental and theoretical data is given below (Figure 6 and Figure 7).

**Figure 6.** Structure amplitude values under the press.

**Figure 7.** Structure amplitude values at 2 m distance from the press.
Table 4. Structure amplitude related to limited dynamic deflection [8].

| Frequency Hz | Amplitude, mm | Frequency Hz | Amplitude, mm |
|--------------|---------------|--------------|---------------|
| 1            | 0.05          | 20           | 0.05          |
| 5            | 0.4           | 25           | 0.04          |
| 10           | 0.04          | 50           | 0.02          |
| 15           | 0.067         | 100          | 0.01          |

The results show that the experimental structure’s amplitudes under the press exceed the limit values obtained according to Table 4. It happens when productivity grows upper than 90000 it/hr (Figure 6). Nevertheless, the amplitudes at 2 m distance from the press position are not critical (figure 7). This fact could be explained by independent functioning of underlying slabs after mortar failure in the structure gaps.

Detailed investigation revealed problems in press supports caused by imperfections as a result of staff incompetence. It led to vibration spreading over load-bearing structures and cracks extension in RC slabs and floor coatings. Subsequent reinforcement works were provided using valuable guidance [10, 11] which is skipped in this paper.

4. Conclusions
This investigation studies the influence of vibration loads on structures during machinery operating. It was resolved as a real case in engineering practice and the following points could be outlined as outcomes:

1) Dynamic deflections caused by operating machine could affect the load-bearing structures even when it was not assumed while designing (e.g. it might occur after technical modernization of enterprises).

2) Appropriate maintenance is highly important for machinery with vibration processes. In our case the lack of it caused the structural and financial damages, therefore quality assurance demands should be met.

3) Applying the simplified methodology to define the limitations for structure’s amplitude in such complex structures is reasonable to perform prompt solutions.

4) The limit amplitudes have been exceeded significantly (e.g. actual 0.06 mm against allowable 0.03 mm) for slabs under the press. When mortar in structure’s gaps failed the vibration loadings rose up and focused in underlining slabs.

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