Dynamic load assessment of building structures

Alena Rotaru

All-Russian Scientific Research Institute for Civil Defence and Emergencies of the EMERCOM of Russia, 121352 Moscow, Russia

Abstract. The questions of the theory and practice of testing structures with dynamic loads are presented. A concrete example of testing a structure on its physical model by dynamic load is clearly shown. Some information necessary for statistical processing of research results is given.

Building structures are exposed to the intensive dynamic loads. The existing methods and regulatory requirements should consider the loss of strength subject to dynamic impacts. The dynamic load types will show what needs to be more focused on during the construction. Building structures should be designed to stay out of the resonance band during the use.

Nowadays, the construction of new industrial complexes and modernization of factories is widely developing. Increased production leads to increased loads, including load-bearing structures of buildings and structures, namely there are dynamic effects from a large number of machines and mechanisms. Dynamic loads are very varied in nature. They include impacts associated with natural phenomena, such as seismic shocks and wind gusts, as well as dynamic impacts of technological and accidental origin. The most important characteristic determine behavior of buildings and structures under the action of external dynamic load, and are frequency, and nature of vibration. All methods for calculating wind and seismic loads are based on determining these parameters.

The purpose of this paper is to demonstrate the effects of dynamic loads on strength, durability, rigidity and crack resistance of building structures; to develop measures for mitigating oscillations; to verify the design performance of commercialized and exploited structures by the frequency and attenuation intensity of natural oscillations. The scientific novelty in this paper is that experiments were conducted to assess the dynamic stability and deficient dynamic stability using the "soil-to-building".

1 Introduction

A dynamic load acts on a building over a short period of time, often with a large and abrupt different values and at different locations. The dynamic load of a building generates internal forces depending on its mass internal forces depending on the building mass and it is not always and it is not always the case that the magnitude of the deformation corresponds to the magnitude of the applied force. The dynamic load is accompanied by the acceleration of the particles of the body in question or of the parts in contact with it. They can arise, disappear...
2 Materials and methods

Dynamic loads are created by people in buildings, trucks on a bridge.

Fig. 1. Fixed load (source: https://infopedia.su/14x147a6.html)

Moving load adapts its position to the structure. (e.g., rail or automotive vehicles (Figure 2)). The moving load is the transport, the train moving over the bridge. The forces depend on the position of the moving load. In order to determine the design values of the forces it is necessary to choose the element to be calculated will be in the most unfavorable conditions. The moving load solves several problems: to determine the most dangerous and the largest (design) position of the load, to calculate the structure for the design load.

Fig. 2. Movable load. (source: https://infopedia.su/14x147a6.html)

Impulse load affects the structure during a sufficiently small period of time as a result of a gas explosion (Figure 3). Impulse load represents short-term forces and impacts occurring during the operation of mechanisms and handling equipment, leading to some reduction in the operational qualities of the structure, but not causing their destruction. Most of these impacts lead to microplastic deformations of the material, which is the main reason for the dissipation of energy of dynamic impact. The necessity of calculations for moderate impulse loads is mainly due to compliance with the level of structural vibration required by sanitary norms and technological requirements.

Fig. 3. Impulse load. (source: https://infopedia.su/14x147a6.html)
Impact load is created by falling objects, hammers and other impact mechanisms (Figure 4). A shock occurs when one object falls on top of another or when there is a rapid change in pressure between these objects. All this seems strange, because if an object, let it be a stone, which has a mass of 5 kg, will not change its mass neither after, nor before, nor at the moment of falling. However, every object has an inert mass as well. It is also called inertial or inertial mass. These studies also show that gravitational mass and inertial mass are equal. And when it comes to impact loads, it is the inertial mass that creates the load, not the gravitational mass.

Fig. 4. Impact load. (source: https://infopedia.su/14x147a6.html)

The dynamic component of wind load, as triggered by draft head pulsation, is taken into account in calculating the high-rise structures with a natural duration of oscillations over 0.25 s, e.g., multi-story buildings about more than 40 m high, one-story single-bay production buildings about more than 36 m high, open stack frames, conveyor galleries, masts, towers, chimneys, power line supports, and other structures (Figure 5).

Fig. 5. Vibration of chimneys under the wind. (source: https://infopedia.su/14x147a6.html)

Seismic load is manifested as irregular displacements and fluctuations of ground, earthquake tremors and shocks (Figure 6). The magnitude of the seismic load is in most cases determined by earthquake analysis and depends on:

- The intensity, duration, and frequency characteristics of the expected earthquake;
- The geological conditions of the construction site;
- Dynamic parameters of the structure.

Seismic load occurs at the contact surfaces of a structure with the ground, either with a neighboring structure or with an earthquake-generated tsunami gravity wave. It constantly tests the seismic resistance of a structure and sometimes exceeds its ability to withstand it without serious damage to the supporting elements of the structure.

Fig. 6. Seismic load. (source: https://infopedia.su/14x147a6.html)

I.e., dynamic load is caused by vehicles, explosions, impacts, wind guts and seismic effects.
3 Results

Fig. 7. Vibration of decaying oscillations.

The dynamic load oscillates the structure. The energy dissipation results in the attenuating vibration record of such oscillations (Figure 7).

The full cycle time and is the oscillation period. The number of oscillation cycles per time unit represents \( f = \frac{1}{T} \) and is the oscillation frequency. The number of oscillations per \( 2\pi \) seconds is the wave circular frequency: \( \omega = \frac{2\pi}{T} \).

The oscillation attenuation degree is the ratio:

\[
\alpha = \frac{\delta}{T} = \ln \frac{a_n}{a_{n+1}} \div T
\]

The dynamic load is classified as function of the magnitude and nature of the external effect. Classes I and II include weak and moderate impulses \( S = \{10...100\} \text{ N} \cdot \text{s} \), while classes III and IV include strong and very strong ones \( S = \{100...1000\} \text{ N} \cdot \text{s} \).

Oscillations triggered by an external disturbing and continuing force are the forced oscillations. The forced oscillation and the disturbing force periods are equal. The amplitude is not dependent on the initial conditions. The disturbing force frequency may be even time-varying. The proximity or match-up between the disturbing force frequency and the natural oscillation frequency of a structure robustly increases the amplitude, which is attributable to the resonance phenomenon.

The data on the “soil-building” dynamic parameters, building’s design, geometry and technical condition were used to assess the dynamic stability and the deficient dynamic stability of the building. The predominant frequencies on the axes of the soil mass in the building’s base are:

- \( F_x = 1.25...2.1 \text{ Hz} \)
- \( F_y = 1.8...2.1 \text{ Hz} \)
- \( F_z = 0.95...2.8 \text{ Hz} \)

The soils in the building’s base with frequencies about 1...2 Hz on axes X, Y and Z are soft earth soils (Figures 8 to 10). Let us assume the dynamicity of the site as 0.5...1 m/s^2.
Fig. 8. Effect on building during the passage of a heavy truck on the X axis (source: by the author)

Fig. 9. Effect on building during the passage of a heavy truck on the Y axis (source: by the author)

Fig. 10. Effect on building during the passage of a heavy truck on the Z axis (source: by the author)
4 Discussion

- Dynamic load is caused by machines and equipment with unbalanced masses, vehicles, explosions, wind gusts in building structures. Under the action of the dynamic load causes the deformation of the structural elements of the building and reduces the reliability of their anchoring nodes. The rate of deformation, among other things, has a considerable effect on the mechanical properties of materials. In all materials with the increase of the strain rate deformation rate increases the strength characteristics and plasticity characteristics decrease, i.e. the material becomes stronger and more brittle, the elastic characteristics remain practically unchanged. If the material is brittle, then collapse occurs, so in calculations of strength under the dynamic action of forces the allowable stresses are taken lower than under static loading conditions, thereby increasing the safety factor of the structure. One of the most dangerous impulse loads on buildings and structures occurs during pile driving on construction sites. Quite often buildings and structures in the area of new construction can be damaged by pile driving damage when there is no control over the changes in their technical condition.

5 Conclusion

- In determining the loads on the existing structures it is necessary to use the actual data on the own weight of technological equipment and building materials, since the adoption of standardized values of these values established for the design of newly built structures leads to a significant overestimation of the actual loads and, consequently, unjustified and costly strengthening of structures. The building is in an emergency state, with resonance oscillations observed in the soil mass, which may lead to the growing displacement amplitudes of loose nodes joining the building’s structural members. The dynamic stability test results of the building show a deficit of dynamic stability in that building. Dangerous oscillations on axis X exhibit during the passage of a heavy truck.

References

5. L.P. Hansen, Dynamics of Structures (Aalborg University, 1994)