Oscillations of Slabs Supported on Point Supports

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Abstract. The urgent task which is addressed in this work is the development of methods for determining the frequencies and forms of vibrations, as well as dynamic reactions of thin slabs with various support systems, including those supported on point supports. The aim of the work is to develop experimental methods for determining the frequencies and forms of natural oscillations of slabs with holes and thin point-supported square solid ones. In this work, the frequencies of square slabs with free edges resting on point supports are determined; the dependences of the vibration frequencies of slabs from the coordinates of point supports and the dimensions of symmetrically placed holes; the arrangement of point supports, wherein the basic frequency of free vibrations of the slab is maximum; the frequencies, shapes, and decrements of vibrations of square slabs supported on four point supports were determined experimentally, as well as the influence of the presence of holes and the degree of pinching of the supports on the dynamic characteristics of these slabs. The article deals with the method and analysis of results of experimental investigations of dynamic characteristics of square solid slabs with holes. Comparison of experimental and theoretical values of frequencies of natural oscillations of slabs showed their good similarity. The results of this work can be applied to dynamic and seismic calculations of point-supported square slabs.

1. Introduction

The study of the work of thin slabs under the influence of dynamic load has long been in the focus of researchers. Thin slabs are one of the main elements of buildings and structures. Slabs with various design solutions and supporting devices are used in coverings and ceilings of residential, public and industrial buildings, as well as in engineering structures. Depending on the purpose and architectural and planning solutions of the building, the slabs may have different shapes and support systems, as well as openings of different shapes. Supports for slabs are usually walls or columns-point supports. Slabs are supported by columns in girder-free ceilings, which are used in buildings of various purposes and in individual structures.

Numerous theoretical and experimental studies are devoted to slab bending. Relatively complex and little-studied objectives are the study of vibrations of slabs. Irregular shapes, a complex system of
support, and the presence of holes complicate the calculation of slabs, especially under dynamic influences.

Account dynamic effects are taken into when calculating structures is especially necessary in conditions of high seismicity. As shown by the analysis of the effects of earthquakes, the maximum acceleration of the vertical component is about the same order as the acceleration of the horizontal component. This indicates that the load-bearing capacity of floor slabs and other structures must be checked taking into account the vertical component of the seismic impact. Therefore, for dynamic and seismic calculations of point-supported slabs used in the construction of buildings and structures, it is of practical interest to determine their dynamic characteristics, frequencies, forms of natural oscillations and decrement of attenuation. Theoretical studies of this problem are usually performed using approximate calculation methods [1, 2, 3, 4, 5, 6, 7].

2. Methods
Determination dynamic characteristics, frequencies, forms of natural oscillations and decay decrement is important components for dynamic and seismic calculations of point-supported slabs used in the construction of buildings and structures. Theoretical studies of the task are usually performed using approximate methods of calculation [8, 9, 10, 11, 12, 13, 14].

In order to check the values of the results of theoretical studies of oscillations of point-supported slabs and clarify certain issues, experimental studies were carried out on models of solid and through steel square slabs supported on four point supports with hinged and pinched support devices, at different locations of coordinates of point supports. The slabs were made of steel sheets with dimensions of 1200x1200 mm and a thickness of 8 mm (Fig.1). Solid slabs with the coordinates of the location of point supports Xc=Yc=580, 400 and 300 mm were designated P-1, P-2 and P-3 (Fig.1A), slabs with square holes (Fig.1B) respectively P-4, P-5 and P-6, and slabs with rectangular holes (Fig.1C) P-7, P-8 and P-9.

![Figure 1](image)

So, nine slabs with different design solutions were tested. In view of the fact that all sizes were tested in the conditions of hinged and pinched support, hereinafter to the designations of slabs with hinged supports were added the letters "s" (P-1s; P-2s, etc.), and to the slabs with pinched supports "z" (P-1z; P-2z, etc.).

Hinge joints were made by steel hemispheres d=30 mm, installed in the head parts of the support pillars, and pinching made with compressible nuts, installed on the slabs in the head parts of the supports.

For static and dynamic testing of the slabs, a special installation was designed and manufactured, whose simplified scheme is shown in (Fig.2). The installation consists of a test table (1), support racks (3) for fixing the test slabs (2), an electrodynamic linear vibrator (4), a generator (5), measuring the
values of electric current frequencies, a current amplifier (6) and other devices necessary for the test. Tests of slab vibrations and formation of free vibrations were carried out using a load $F=250$ N, hung in their center. The forced vibrations of the slabs were excited by electrodynamic vibrators, which were powered by a low-frequency generator of the G6-15 brand. By means of the latter, a smooth increase in the frequency of the current transmitted to the vibrator in the tested slabs, different vibration frequencies (including resonant ones) arose, which determined the dynamic characteristics of the natural vibrations of the slabs.

![Figure 2](image)

Figure 2

Static tests of slabs were carried out to determine their stiffness, in order to verify the results of dynamic tests. Dynamic tests were carried out in two stages. The first stage determined the natural frequency of the slabs of the first form in terms of free oscillations, and in the second stage they were subjected to forced oscillations in terms of resonant oscillations and so determined displacements and frequencies at the I, II and III forms of natural oscillations.

The movements and frequencies of free and forced oscillation of slabs were determined by vibrators of the SV-10C brand. The system of measuring devices (Fig.3) consists of a vibrator (1), a resistance box (2) and a HO-441 oscilloscope (3).

![Figure 3](image)

Figure 3

3. Results

Experimental values of deflections and frequencies of the tested slabs are given in table 1.

| Slabs | Deflection, mm | Frequency of free oscillations, Hz | Frequencies by forms of oscillations, Hz |
|-------|----------------|----------------------------------|----------------------------------------|
|       |                |                                  | I form | II form | III form |
| 1     | 2              | 3                                | 4      | 5       | 6        |
| P-1s  | 1.75           | 12                               | 11.1   | 23.0    | 64.0     |
| P-1z  | 1.10           | 15                               | 15.5   | 29.3    | 68.0     |
| P-2s  | 0.38           | 26                               | 26.0   | 50.0    | 90.5     |
| P-2z  | 0.25           | 31                               | 30.0   | 54.5    | 94.6     |
| P-3s  | 0.21           | 32                               | 30.5   | 44.0    | 86.3     |
| P-3z  | 0.15           | 37                               | 35.0   | 48.3    | 90.0     |
| P-4s  | 2.65           | 10                               | 10.5   | 23.0    | 72.0     |
In order to verify the results of theoretical studies of the point-supported slab oscillations from the graphs given in [15], the theoretical values of the vibration frequencies of the studied slabs were determined, which were compared with the corresponding values of the frequencies determined experimentally (table 2).

| Slabs | Values of frequencies of natural oscillations, Hz |
|-------|------------------------------------------------|
|       | I form              | III form         |                     |
|       | Theoretically       | Experimentally   | Theoretically       | Experimentally   |
| P-1s  | 11,0                | 11,1             | 63,5                | 64,0             |
| P-2s  | 24,2                | 26,0             | 89,8                | 90,5             |
| P-3s  | 27,4                | 30,5             | 91,2                | 86,3             |
| P-4s  | 10,0                | 11,0             | -                   | 72,0             |
| P-5s  | 28,0                | 28,5             | -                   | 83,0             |
| P-6s  | 30,9                | 29,0             | -                   | 80,0             |

Straight-line displacements were measured at 170 points on their surfaces in order to construct the vibration patterns of the slabs. Relative values (δ i / δ max) were determined from the displacement oscillograms and I, II and III forms of slab oscillations were constructed. (fig.4,5,6,7)

Due to the slight influence of the shape and size of the holes on the dynamic characteristics of the slabs, only some of the test results of solid slab are given below.
Figure 4

Figure 5
4. Discussion
The data analysis shown in table 1 shows that fixing supports leads to an increase in the stiffness of the slabs and, accordingly, to a change in frequencies. The degree of stiffness increase depends on the positioning of the supports: when the location of the supports in the corners of the slabs (P-1, P-4, P-7)
stiffness increased on average by 1.6 times, during the installation of pillars coordinates Xc=Yc=400 mm (P-2, P-5 and P-8) by 1.51 times, and in the case of Xc=Yc=300 mm (P-3, P-6, P-9) by 1.34 times. In proportion to the change in stiffness, the natural oscillation frequencies of the slabs also increased.

Comparison of the results of theoretical and experimental values of the natural oscillation frequencies of slabs (table 2) shows they are very similar in value and differ on average by 6% for fluctuations in the I form, and by 2.5% for fluctuations in the III form. Such proximity of theoretical and experimental values of oscillation frequencies testifies to the reliability of the solution of the theoretical problem.

The first form of oscillation of a solid slab (P-1s) along its separate axes in the form of axial lines is shown in figure 4. In the joint consideration of the constructed center lines (Fig. 4A, b) the I form of slab oscillation is a two-sided shell supported by four points II and III forms of slab oscillation (Fig. 5 and 6) in space are shells with positive and negative curvature, supported by four points. I the oscillation form with cantilever parts (P-2s) is also a two-sided shell (Fig.7).

The values of the slab vibration decrements were determined from the oscillograms of damped oscillations and from the resonance curves. According to the results of experimental studies, the decrement of attenuation depends on the conditions of fixing the supports of the slab and the shape of the oscillations. So, for example, the value of the decrement of slabs with a hinge support for fluctuations in I, II and III forms was 0.072, 0.047 and 0.038, and for slabs with a pinched support for fluctuations of the first three forms, respectively, 0.065, 0.043 and 0.036. So, the decrement of oscillations at the hinge support of the slab in comparison with the pinched support turned out to be approximately 10% more.

5. Conclusion

The values from the data given in columns 3 and 4 of table 1 of the received frequencies of free and forced (resonant) oscillations are almost identical and differ from each other by an average of 4.5%. This fact confirms the reliability of the frequencies determined by resonant vibrations.

Moreover, from the data given in table.1 it is also obvious that the presence of holes and their appearance do not have a significant impact on the oscillation frequency, despite the fact that the rigidity of the latter varies significantly (for the slabs with square holes by 1.43-1.51 times, and for slabs with rectangular holes by 1.33-1.43 times). An insignificant change in frequency can be explained by the fact that the presence of holes simultaneously with a decrease in the stiffness of the slabs reduces its mass.

The proximity of theoretical and experimental values of oscillation frequencies (table 2) indicates the reliability of the solution of the theoretical task.

So, the decrement of oscillations at the hinge support of the slab in comparison with the pinched support turned out to be approximately 10% more

As for the dependence of the decrement of the oscillation on the form of oscillations, it decreases accordingly to the increase in the degree of oscillations.

6. References

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