11 WCEE

Published by Elsevier Science Ltd 1996
Paper No. 1188. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

DETERMINATION OF BUILDINGS CONDITION BY THEIR DYNAMIC CHARACTERISTICS

A. Zolotcov, Prof., Dr. Eng., General Director,

National Center for Research and Standardization "CERCON"
N. Milescu Spataru 9, apt. 168, Kishinev, 277042, Republic of Moldova

ABSTRACT

A modern building is a complex construction system maintained over a long period of time (100-150 years). Within this period there inevitably arises the necessity in assessing serviceable (physical) condition of the building. Such an assessment is usually carried out on the basis of a long comprehensive engineering inspection of the building.

It is quite natural, that organization of a large-scale stock-taking of the building, especially within the shortest possible time (e.g. after the earthquakes), is associated with resolving of serious difficulties. As the case stands, there appears an insistent need for timely estimation of physical condition of the buildings, degree of accuracy being sufficient for practical purposes. Such an assessment can be made by analyzing dynamic characteristics of the building, in particular its natural frequency period. Knowing the correlation between the above mentioned parameter and physical state of the building, one can define the damage the building has suffered and decide whether the structure in question needs to be reinforced. Reinforcement being accomplished, one can evaluate its effectiveness.

KEYWORDS

SEVERITY OF DAMAGE TO THE BUILDING. NATURAL FREQUENCY PERIOD. ITS PARTIAL COMPONENTS. RELIABILITY OF SERVICEABLE CONDITIONS OF THE BUILDING.

The scientists who studied earthquake resistance of the buildings have pointed out on several occasions that changing of physical condition of the building entails changing of its dynamic characteristics as well. Some of the investigators even made attempts to establish approximate correlation between the severity of damage to the building and dynamic characteristics of the latter. As a rule, the main representative characteristic analyzed was natural frequency period of the building. However quantitative discrepancy of the results of these attempts hampered the progress of their practical realization. Thus, according to the findings of some investigators the natural frequency of the building at failure exceeds its initial value 1.2-1.4 times. Some other investigators declared this coefficient to be even greater (2-2.7). Such disagreement as concerns one and the same phenomenon can be explained by several circumstances of fact.
First of all, different scientists had to do with different subjects of inquiry. Secondly, experimental procedures for such investigations were not adequately substantiated and stabilized. Thirdly, in the progress of these investigations there was examined dynamic response of the "building-subsoil interaction" system and not that of the "building as it is".

It is clear that the relationship between physical condition of the building and its dynamic response is a multi-factor dependence, which is a function of such characteristics as height of the building, its overall dimensions, vertical loading magnitude, strain capacity of materials the main constructions of the building are made of, structural features of the materials in question, etc.

Such factors as pitch, decrement and wave form of natural frequency may serve as important characteristics of the building. It is most convenient to use the first characteristic mentioned, as this characteristic is easy to be determined experimentally. According to the experiments carried out, oscillations decrement is a less stable parameter. As regards the wave form of vibrations, investigation of it is a somewhat more difficult engineering problem than determination of natural frequency of the building. Moreover, analysis of the oscillations wave form may indicate the location of severe damages in the building, but it can hardly allow evaluation of their gravity. Thus, natural frequency of the building shall be considered the main dynamic criterion of the building's physical condition estimation, other dynamic characteristics to be engaged, should there arise the necessity to go deeper into solution of the problem.

In order to reveal the relationship between the physical condition of the building and its natural frequency (T) the author has carried out a range of experimental (full-scale and laboratory) and theoretical investigations, some results of which are presented in the given paper.

Theoretical Basis for Assessing Physical Condition of the Building by its T-Value

The building vibrating, there come into action elastic resistance and viscous friction forces as well as cohesive forces in the cracks and the force of subsoils resistance. Temporal variations of any of the above factors can result in changing of T-value.

Thus, T-parameter shall be considered the function of a set of independent variables.

In the course of time the building develops plastic deformations, and there appear various defects in structures and there connections. As the result, the physical condition of the building and in particular its load-carrying capacity and stress-strain behavior change under the action of such factors as earthquakes and non-uniform subsidence of subsoils under the foundation. These parameters may undergo discontinuous change reaching the limits when normal maintenance of the building becomes no longer possible.

While development of plastic deformations and appearance of defects in building's structures lead to enlargement of T-value, changing of subsoils properties in the course of time may have an opposite effect. Accordingly, changing of deformation properties of the building and its foundation, if taking simultaneous effect, may cause various changes regarding natural frequency of the "building-subsoil interaction" system. That is why differential formulation of the task to solve this problem is impractical. In this case one should direct one's attention to average statistical dynamics of damages different types of buildings suffer under natural disasters.

As concerns the task set, while the authors were interested in determining such factors as physical condition of the building, it became necessary to separate from the aggregate change of T-value in the "building-subsoil" system the part determining transformation of the building's characteristics.

Let us use for this purpose Dunkerley formula, representing it by equation

$$T_{(f)} = \sqrt{T_b^2{}_{(f)} + T_x^2{}_{(f)} + T_\varphi^2{}_{(f)}}, \qquad (1)$$

where $T_{(f)}$ = natural frequency of the damaged building;

$T_{b(f)}, T_{x(f)}, T_{\varphi(f)}$ = partial periods of natural frequency conditioned, correspondingly, by development of plastic deformations in the building, its sliding over the ground and oscillation on the subsoil.

Let us represent $T_{b(f)}$ in the form of

$$T_{b(f)} = T_{b(0)} + \Delta T_b, \tag{2}$$

where $T_{b(0)}$ = partial period of natural vibrations of the undamaged building, the value depending on the deformation of the building;
$\Delta T_b = T_{b(0)}$ partial period increment owing to the fact that the building's structures develop damages and plastic deformations.

Subject to (2) formula (1) takes the form

$$T_{(f)} = \sqrt{(T_{b(0)} + \Delta T_b)^2 + T_{x(f)} + T_{\varphi(f)}}, \tag{3}$$

from which

$$\Delta T_{(b)} = \sqrt{T^2_{(f)} - T_x^2{}_{(f)} - T_\varphi^2{}_{(f)}} - T_{b(0)} \tag{4}$$

$T_{(f)}$ value is determined experimentally during inspection of the building, while Tb(0) value is calculated with the aid of the formula

$$T_{b(0)} = \sqrt{T^2_{(0)} - T_x^2{}_{(0)} - T_\varphi^2{}_{(0)}}, \tag{5}$$

where $T_{(0)}$ = natural frequency period of the undamaged building. This value is determined experimentally after commissioning of the building or sometimes, as an exception, by making calculations.

$T_{x(0)}$, $T_{\varphi(0)}$ = partial periods of natural frequency of the undamaged building conditioned, accordingly, by the sliding of the building over the ground and its oscillation on the subsoil.

In the general case T_x and T_φ values can be estimated from equations

$$T_x = 2\pi\sqrt{\frac{Q}{k_x g}}\ ; \qquad T_\varphi = 2\pi H\sqrt{\frac{0.33Q}{k_\varphi g}}, \tag{6}$$

where Q = weight of the building;
g = free fall acceleration;
H = height of the building;
k_φ, k_x = foundation shear and torsion stiffness factors

$$k_x = C_x F\ ; \qquad k_\varphi = C_\varphi I, \tag{7}$$

where C_x = elastic uniform shear factor;
C_φ = elastic non-uniform compression coefficient;
F = base of foundation surface area;
I = moment of the foundation base inertia about horizontal axis.

There exist several ways to determine C_x and C_φ coefficients. According to the former USSR Building Code

$$C_x = 0.7C_zF\ ; \qquad C_\varphi = 2C_zI\ , \qquad (8)$$

where C_z = elastic uniform compression coefficient. For foundations with $F<200\ m^2$ it is to be calculated by the formula

$$Cz = b_0E(1 + \sqrt{\frac{10}{F}}), \qquad (9)$$

where $b_0 = (m^{-1})$ coefficient, which is taken equal to 1 for sand; 1.2 for sandy loam and loam; and 1.5 for clay and coarse fragment soils;

E = soil deformation modulus (t/m^2).

The foregoing signifies that in order to assess physical condition of the building (its serviceable condition reliability) it is necessary to determine the value of ΔT_b. Knowing the relation between ΔT_b for certain types of buildings and their damage class, one can answer the question whether the building needs reinforcement of some structures for its further normal maintenance.

One can consider it necessary for the most critical structures to be reinforced, should they have class 2 damages; for ordinary buildings - after 2-3 class damaging and for the buildings designed without taking into account special impacts - after class 3 damaging.

EXPERIMENTAL INVESTIGATIONS

Among the experimental investigations carried out by the author, full-scale experiments account for the most part of research. Among the latter there are long instrumental observations of the (T_b) change on sample of more than 50 buildings of various structural design, the height of the building being 5-22 storeyed, and full-scale vibration-survival dynamic testing of buildings and their sections.

The last vibration-survival destruction tests have been carried out on specially erected monolithic building 6-storeyed sections in Kishinev*). In the course of these tests it was found out that natural frequency of the "building-subsoil" system grew smoothly with the rise of inertial load up to the formation of first cracks in the walls of the building. Appearance of first cracks and their propagation has lead to the abrupt rise of T-value (Fig. 1).

Similar result has been registered on carrying out observations of a large number of buildings maintained. The reader is referred to Fig.2 to see examples of observations' results obtained on three buildings. One of them - a 7-storeyed frame-stone building built in 1972 - endured 3 severe Carpathians earthquakes (1977, 1986 and 1990) without suffering any noticeable damages. Its natural frequency grew smoothly in accordance with general ageing of the building: for 22 years of maintenance this factor has grown in longitudinal and lateral directions 30% and 22% respectively.

Two monolithic buildings built in 1973-1976 had suffered 2 and 3 class damages during the earthquakes of 1977 and 1986; owing to the effect of the earthquakes the values of their natural frequencies have risen abruptly (up to 40%).

---

*) See the paper of the author and Yu.Izmailov "Vibrational tests on sections of monolithic buildings at high levels of loading" in the present Proceedings.

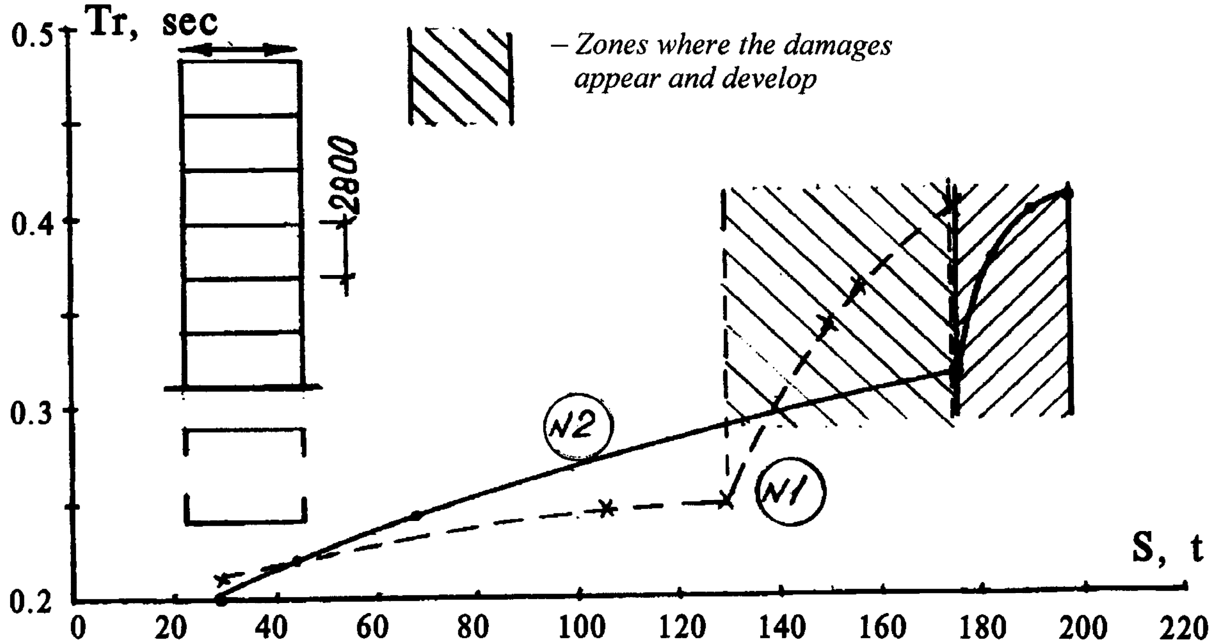

Fig. 1. **Changing of the period of resonance vibrations of two 6-storeyed sections of monolithic buildings related to the growth of inertial loading**

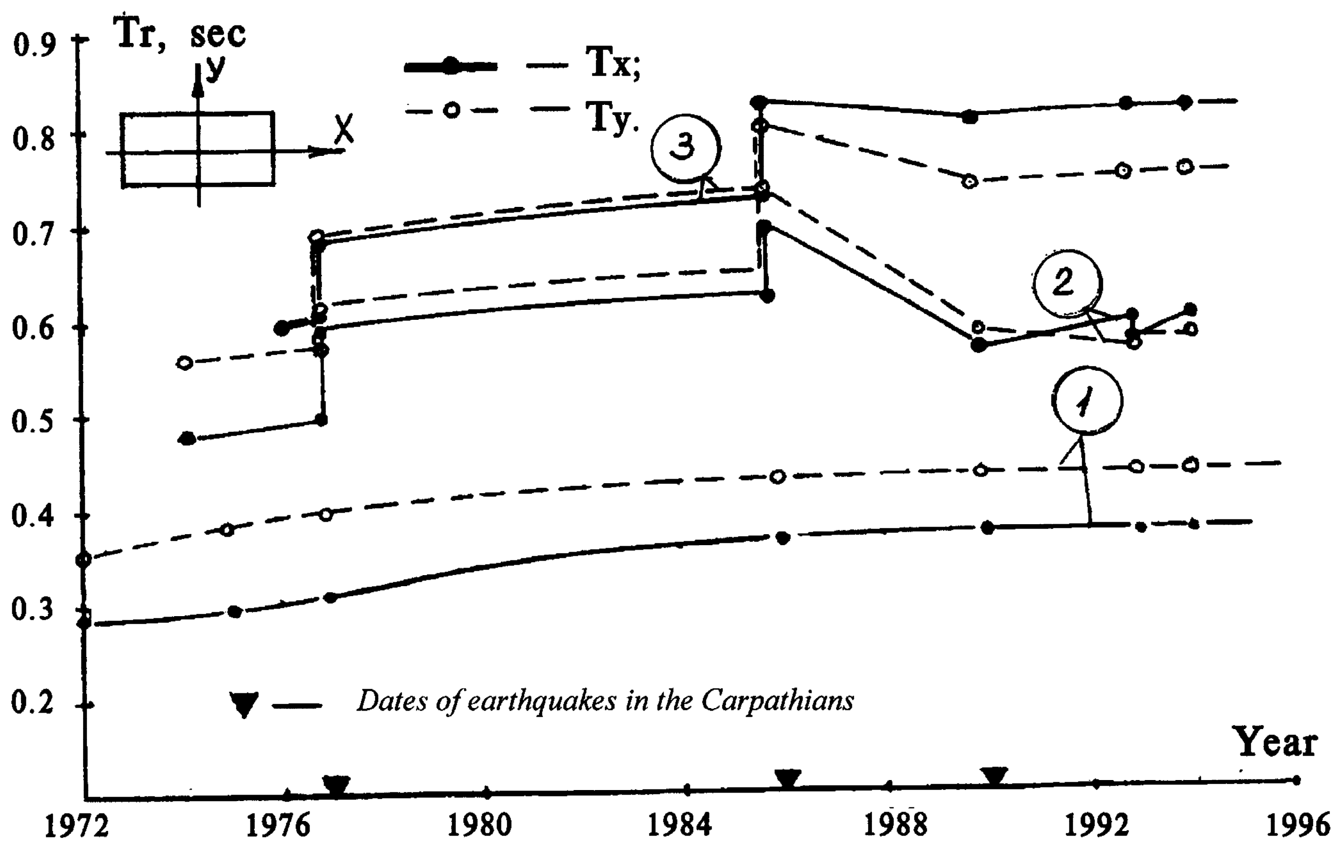

Fig. 2. **Changing of the natural frequency of the buildings**
1 - 7-storeyed frame-stone building
2 - monolithic 11-storeyed building
3 - monolithic 16-storeyed building

It is of interest to note that after the abrupt rise of T-value of the "building-subsoil interaction" system there comes relaxation of the value in question. One can attribute it to deformation processes taking place both in the structure of the building and in its foundation material when they experience powerful action of forces. It is natural that though the damages in the building's structures are not recovered, their influence upon dynamic parameters of the building can change due to closing or propagation of some cracks, deformation of reinforcing rods, etc. It is necessary to take this fact into account when making assessment of physical condition of the building.

THEORETICAL RESEARCH

In contrast to full-scale experimental determination of natural frequencies of the buildings performing jointly with foundation, theoretical research makes it possible to determine net partial period of natural frequency of the building (T_b) and its increment (ΔT_b).

As an instrument for such a research there was used "NELIN" program, realizing finite elements method in non-linear formulation. With the help of this program there was calculated a package of problems describing buildings of different height, under a wide range of vertical loading, with openings in the walls, with blind walls, buildings being made of materials having various deformation characteristics, etc.

Calculations for each problem were made taking account of the following: constant vertical loading and stepwise rise of the horizontal seismic loads up to the moment when the construction system load-carrying capacity reaches the limit.

Theoretical investigations showed that initial changing of the building's walls stress-strain modulus results in a smooth and not very marked increase of Tb, but with the development of first cracks the intensity of Tb change grows substantially (Fig. 3). By the moment of collapsing of the structure the value of natural frequency $T_{b(f)}$ exceeds $T_{b(0)}$ 1.75-2.15 times.

One can see that the data of theoretical research are in good agreement with the corresponding experimental evidence.

As to the graphs in Fig. 3, the rise of partial period of frameless buildings natural frequency, the structures suffering 1, 2, 3 and 4 class damages, can be characterized as follows: 15-20, 30-40, 40-60 and 60-80% respectively.

At present the author completes the work on developing practical procedures for the assessment of physical condition of structures as regards service conditions reliability of frameless buildings, by their experimental dynamic characteristics.

This methodology makes provisions for not only assessing the class of damage the buildings suffer but also for determination of these damages location. In addition, the methodology in question makes it possible to assess the effectiveness of the already completed strengthening of the damaged constructions.

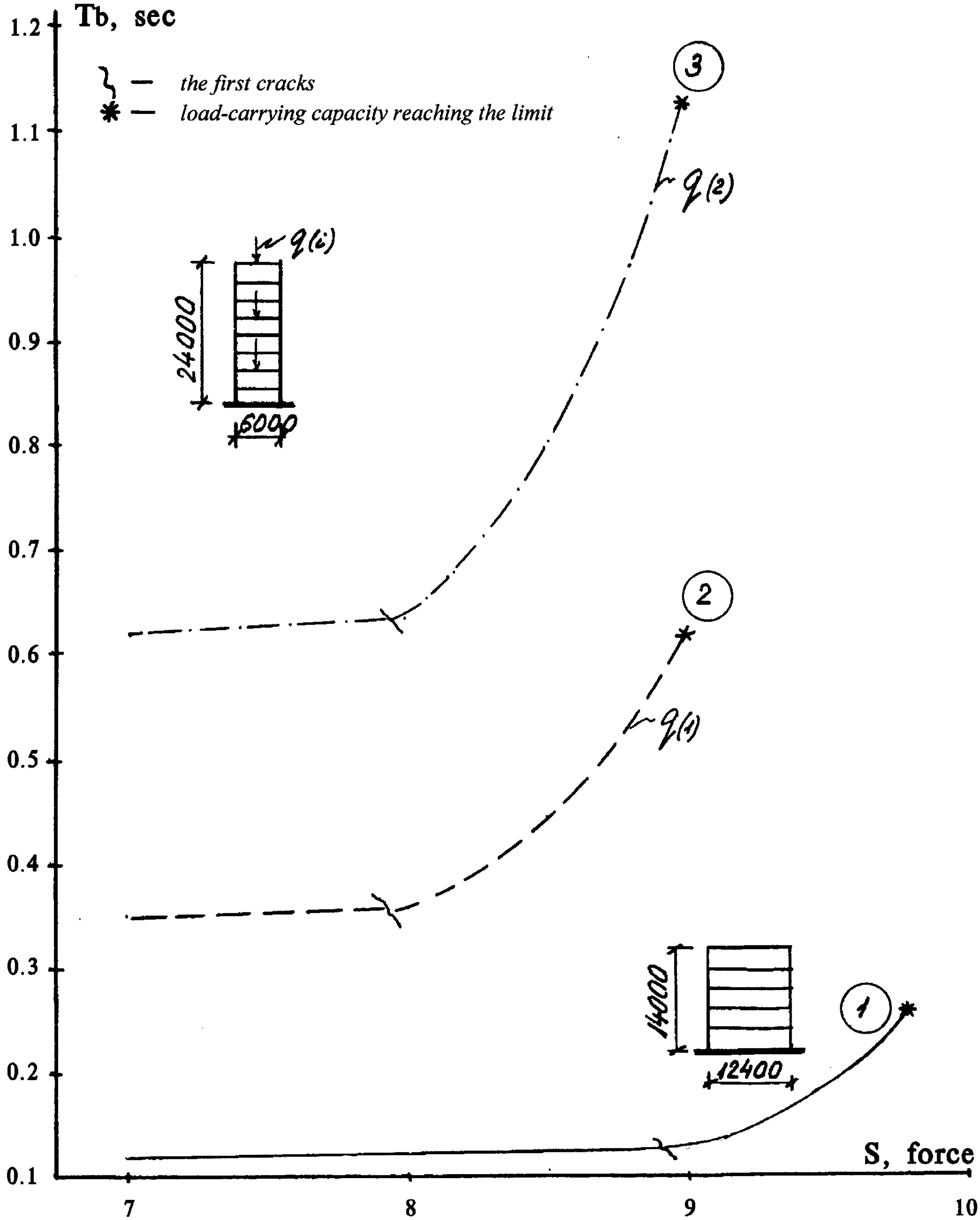

Fig. 3. **Changing of the partial period of natural frequencies (Tb) of monolithic building's walls plotted against the seismic loading growth**