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Structural Mechanics

Experimental-Analytical Method Based on the General Principle of Mechanics for Studying the Behavior of the Existing Building during an Earthquake

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In recent years, high-rise constructions are intensively built in seismically active areas worldwide (US, Canada, Japan, Chili, Europe, etc.) accompanied by the development of the respective regulatory framework. According to the authoritative experts, it is not appropriate for high-rise buildings to use current regulatory requirements based on the summarized experience of the seismic behavior of low-rise buildings during seismic loading. The principles of seismic safety of high-rise buildings have not been conclusively formulated yet. It is necessary to make new building regulations. Consequently, there is a big experimental testing ground in seismic areas of the world, where the high-rise buildings are constructed waiting for experimental testing during real earthquakes. The necessity of testing of the seismic stability of high-rise buildings experimentally without awaiting for testing by real earthquake comes to the fore in the described situation. In the paper, an algorithm is developed based on the relevant experimental data using the principle of work reciprocity known in mechanics for determining the behaviour of the object during the passage of any seismic wave through its base. *© 2021 Bull. Georg. Natl. Acad. Sci.*

High-rise buildings, general principle of mechanics, earthquake

I would like to begin with a quote from professor Nemchinov’s fundamental monograph [1]: “Existing experience and earthquake engineering design standards applicable in countries of the world were based on the experience of the analysis of consequences for low-rise buildings and, in this regard, existing standards and recommendations do not reflect contemporary understanding of demands in respect of high-rise buildings.”

“Formulation of principles of estimation of earthquake safety of high-rise buildings is not fully completed yet” [1].

It obviously comes to mind that an experimental polygon is being prepared over a vast area of the Earth’s surface and the high-rise buildings constructed there are waiting for experimental testing during real earthquakes. The necessity of testing of the seismic stability of high-rise buildings experimentally without awaiting for testing by a real earthquake comes to the fore in the described situation.

The above-mentioned encyclopedic monograph considers different approaches to existing experimental methods for estimation of seismic

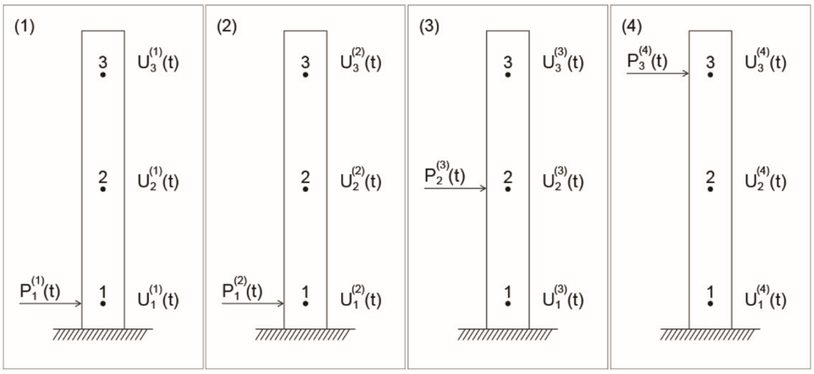

Fig. Dynamical processes of a building.

stability of existing buildings. We also have publications on the subject [2, 3]. In the present paper we propose an experimental – analytical approach based on the principle of work reciprocity estimation of building behavior during earthquake impact.

Let us first consider the general case of some dynamical processes of building vibration. The Figure shows simplified scheme of a building in which 4 design points are marked.

During the (1) dynamical process a construction is affected by seismic wave $U_1^{(1)}$ (t) that causes displacement in other points $U_2^{(1)}$ (t) and U_3 $^{(1)}$(t) which are to be defined.

During the (2) dynamical process a construction is affected by the known dynamic force $P_1^{(2)}$ (t) that causes known (measured) displacement $U_1^{(2)}$ (t).

During the (3) dynamical process a construction is affected by the known dynamic force $P_2^{(3)}$ (t) that causes the known (measured) displacements $U_1^{(3)}$ (t), U_2 $^{(3)}$ (t), $U_3^{(3)}$ (t).

During the (4) dynamical process a construction is affected by the known dynamic force $P_3^{(4)}$ (t) that causes the known (measured)displacements $U_1^{(4)}$ (t), U_2 $^{(4)}$ (t), $U_3^{(4)}$ (t).

Used work-reciprocity principle: the work of external forces of the first state on displacements of the second one is equal to the work of external forces of the second state on displacements of the first one [4].

The integral equations used and the corresponding algebraic equations are given below. In the given algebraic equations, the known values are indicated in regular style, and the exploratory values in bold.

The principle for (1) and (2) states can be formulated this way:

$$\boldsymbol{\int_0^t P_1^{(1)}(\tau)\times U_1^{(2)}(t-\tau)d\tau=\int_0^t P_1^{(2)}(t-\tau)\times U_1^{(1)}(\tau)d\tau}$$

$t=1$

$\boldsymbol{\tau=0}$

$\mathbf{P_1^{(1)}(0)}\times\ U_1^{(2)}(1)=P_1^{(2)}(1)\times U_1^{(1)}(0)$

$\boldsymbol{\tau=1}$

$\mathbf{P_1^{(1)}(1)}\times\ U_1^{(2)}(0)=P_1^{(2)}(0)\times U_1^{(1)}(1)$

$t=2$

$\boldsymbol{\tau=0}$

$P_1^{(1)}(0)\times U_1^{(2)}(2)=P_1^{(2)}(2)\times U_1^{(1)}(0)$

$\tau=1$

$P_1^{(1)}(1)\times U_1^{(2)}(1)=P_1^{(2)}(1)\times U_1^{(1)}(1)$

$\boldsymbol{\tau=2}$

$\mathbf{P_1^{(1)}(2)}\times\ U_1^{(2)}(0)=P_1^{(2)}(0)\times U_1^{(1)}(2)$

$t=3$

$\boldsymbol{\tau=0}$

$P_1^{(1)}(0)\times U_1^{(2)}(3)=P_1^{(2)}(3)\times U_1^{(1)}(0)$

$\boldsymbol{\tau=1}$

$P_1^{(1)}(1)\times U_1^{(2)}(2)=P_1^{(2)}(2)\times U_1^{(1)}(1)$

$\boldsymbol{\tau=2}$

$P_1^{(1)}(2)\times U_1^{(2)}(1)=P_1^{(2)}(1)\times U_1^{(1)}(2)$

$\boldsymbol{\tau=3}$

$\mathbf{P_1^{(1)}(3)}\times\ U_1^{(2)}(0)=P_1^{(2)}(0)\times U_1^{(1)}(3)$

$t = 4$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(2)}(4) = P_1^{(2)}(4) \times U_1^{(1)}(0)$$

$\tau = 1$

$$P_1^{(1)}(1) \times U_1^{(2)}(3) = P_1^{(2)}(3) \times U_1^{(1)}(1)$$

$\tau = 2$

$$P_1^{(1)}(2) \times U_1^{(2)}(2) = P_1^{(2)}(2) \times U_1^{(1)}(2)$$

$\tau = 3$

$$P_1^{(1)}(3) \times U_1^{(2)}(1) = P_1^{(2)}(1) \times U_1^{(1)}(3)$$

$\tau = 4$

$$\mathbf{P_1^{(1)}(4)} \times U_1^{(2)}(0) = P_1^{(2)}(0) \times U_1^{(1)}(4)$$

Determined $\mathbf{P_1^{(1)}(t)}$.

The principle for (1) and (3) states can be formulated this way:

$$\boldsymbol{\int_0^t P_1^{(1)}(\tau) \times U_1^{(3)}(t-\tau)\,d\tau = \int_0^t P_2^{(3)}(t-\tau) \times U_2^{(1)}(\tau)\,d\tau}$$

$t = 1$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(3)}(1) = P_2^{(3)}(1) \times \mathbf{U_2^{(1)}(0)}$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1) \times U_1^{(3)}(0) = P_2^{(3)}(0) \times \mathbf{U_2^{(1)}(1)}$$

$t = 2$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(3)}(2) = P_2^{(3)}(2) \times U_2^{(1)}(0)$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1) \times U_1^{(3)}(1) = P_2^{(3)}(1) \times U_2^{(1)}(1)$$

$\boldsymbol{\tau = 2}$

$$P_1^{(1)}(2) \times U_1^{(3)}(0) = P_2^{(3)}(0) \times \mathbf{U_2^{(1)}(2)}$$

$t = 3$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(3)}(3) = P_2^{(3)}(3) \times U_2^{(1)}(0)$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1) \times U_1^{(3)}(2) = P_2^{(3)}(2) \times U_2^{(1)}(1)$$

$\boldsymbol{\tau = 2}$

$$P_1^{(1)}(2) \times U_1^{(3)}(1) = P_2^{(3)}(1) \times U_2^{(1)}(2)$$

$\boldsymbol{\tau = 3}$

$$P_1^{(1)}(3) \times U_1^{(3)}(0) = P_2^{(3)}(0) \times \mathbf{U_2^{(1)}(3)}$$

$t = 4$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(3)}(4) = P_2^{(3)}(4) \times U_2^{(1)}(0)$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1) \times U_1^{(3)}(3) = P_2^{(3)}(3) \times U_2^{(1)}(1)$$

$\boldsymbol{\tau = 2}$

$$P_1^{(1)}(2) \times U_1^{(3)}(2) = P_2^{(3)}(2) \times U_2^{(1)}(2)$$

$\boldsymbol{\tau = 3}$

$$P_1^{(1)}(3) \times U_1^{(3)}(1) = P_2^{(3)}(1) \times U_2^{(1)}(3)$$

$\boldsymbol{\tau = 4}$

$$P_1^{(1)}(4) \times U_1^{(3)}(0) = P_2^{(3)}(0) \times \mathbf{U_2^{(1)}(4)}$$

Determined $\mathbf{U_2^{(1)}(t)}$.

The principle for (1) and (4) states can be formulated as follows:

$$\boldsymbol{\int_0^t P_1^{(1)}(\tau) \times U_1^{(4)}(t-\tau)\,d\tau = \int_0^t P_3^{(4)}(t-\tau) \times U_3^{(1)}(\tau)\,d\tau}$$

$t = 1$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(4)}(1) = P_3^{(4)}(1) \times \mathbf{U_3^{(1)}(0)}$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1) \times U_1^{(4)}(0) = P_3^{(4)}(0) \times \mathbf{U_3^{(1)}(1)}$$

$t = 2$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(4)}(2) = P_3^{(4)}(2) \times U_3^{(1)}(0)$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1) \times U_1^{(4)}(1) = P_3^{(4)}(1) \times U_3^{(1)}(1)$$

$\boldsymbol{\tau = 2}$

$$P_1^{(1)}(2) \times U_1^{(4)}(0) = P_3^{(4)}(0) \times \mathbf{U_3^{(1)}(2)}$$

$t = 3$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0) \times U_1^{(4)}(3) = P_3^{(4)}(3) \times U_3^{(1)}(0)$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1) \times U_1^{(4)}(2) = P_3^{(4)}(2) \times U_3^{(1)}(1)$$

$\boldsymbol{\tau = 2}$

$$P_1^{(1)}(2)\times U_1^{(4)}(1) = P_3^{(4)}(1)\times U_3^{(1)}(2)$$

$\boldsymbol{\tau = 3}$

$$P_1^{(1)}(3)\times U_1^{(4)}(0) = P_3^{(4)}(0)\ \boldsymbol{\times U_3{}^{(1)}(3)}$$

$t = 4$

$\boldsymbol{\tau = 0}$

$$P_1^{(1)}(0)\times U_1^{(4)}(4) = P_3^{(4)}(4)\times U_3^{(1)}(0)$$

$\boldsymbol{\tau = 1}$

$$P_1^{(1)}(1)\times U_1^{(4)}(3) = P_3^{(4)}(3)\times U_3^{(1)}(1)$$

$\boldsymbol{\tau = 2}$

$$P_1^{(1)}(2)\times U_1^{(4)}(2) = P_3^{(4)}(2)\times U_3^{(1)}(2)$$

$\boldsymbol{\tau = 3}$

$$P_1^{(1)}(3)\times U_1^{(4)}(1) = P_3^{(4)}(1)\times U_3^{(1)}(3)$$

$\boldsymbol{\tau = 4}$

$$P_1^{(1)}(4)\times U_1^{(4)}(0) = P_3^{(3)}(0)\ \boldsymbol{\times U_3{}^{(1)}(4)}$$

Determined $\boldsymbol{U_3{}^{(1)}(t)}$.

Thus, the movements of the building are determined on two levels $U_2^{(1)}$ (t), $U_3^{(1)}$ passing any seismic wave $U_1^{(1)}$ (t) through its base.

Conclusion

The paper describes an experimental-analytical method that allows to determine the behavior of an existing building during the passage of a seismic wave of any nature through the base of the building by conducting simple experiments. Without a detailed study, the actual construction scheme of the building, the damping decrement, resonant frequencies, the deformation properties of the materials used and other physical characteristics are taken into account. The method is based on the principles of the relationship of works known in mechanics.

სამშენებლო მექანიკა

მექანიკის ზოგად პრინციპზე დაფუძნებული ექსპერიმენტულ-ანალიტიკური მეთოდი, არსებული შენობის მიწისძვრისას ქცევის შესასწავლად

გ. გაბრიჩიძე

აკადემიის წევრი, საქართველოს მეცნიერებათა ეროვნული აკადემია, ბუნებრივი კატასტროფების სამეცნიერო პრობლემების შემსწავლელი კომისია, თბილისი, საქართველო

ბოლო წლებში მსოფლიოს სეისმურად აქტიურ რეგიონებში გამრავლდა მაღლივი და ზემაღლივი შენობების რაოდენობა, რასაც თანა სდევს ასეთი შენობების დაპროექტების ნორმატული დოკუმენტების შემუშავება სხვადასხვა ქვეყნებში. ცნობილი ავტორიტეტები მიიჩნევენ, რომ ძველ ნორმატულ დოკუმენტებზე დაყრდნობით არ შეიძლება მაღლივი შენობების დაპროექტება.უნდა შეიქმნას მაღლივი შენობების დაპროექტების სპეციალური ნორმები. თუ ამ მოსაზრებას დავეთანხმებით, შეგვიძლია ვთქვათ, რომ მსოფლიოს სეისმურად აქტიური რეგიონები გადაქცეულია ექსპერიმენტულ პოლიგონებად, სადაც მრავალი მაღლივი შენობა რეალური მიწისძვრით გამოცდას ელოდება. ამ პირობებში ძალიან აქტუალური ხდება მოსაზრება, რომ არ დაველოდოთ მიწისძვრებს და არსებული მაღლივი შენობების ქცევა მიწისძვრისას შევაფასოთ ექსპერიმენტული გზით. ნაშრომში აღწერილია ექსპერიმენტულ-ანალიტიკური მეთოდი, რომელიც საშუალებას იძლევა მარტივი ექსპერიმენტების ჩატარების გზით განვსაზღვროთ არსებული შენობის ქცევა ნებისმიერი ხასიათის სეისმური ტალღის გავლისას ნაგებობის ფუძეში. დეტალური შესწავლის გარეშე ხდება ნაგებობის რეალური კონსტრუქციული სქემის, ნაგებობის ჩაქრობის დეკრემენტის, გამოყენებული მასალების დეფორმაციული თვისებების და სხვა ფიზიკური მახასიათებლების გათვალისწინება. მეთოდი დაფუძნებულია მექანიკაში ცნობილ მუშაობათა ურთიერთობის პრინციპებზე.

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