საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 12, №3, 2018
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 12, no.3, 2018

Structural Mechanics

Experimental-Analytical Method of Data Processing during Wind Loading to Determine the Behavior of High-Rise Buildings under Seismic Load

Guram Gabrichidze

Academy Member, Commission of Scientific Problems of Natural Disasters, Georgian National Academy of Sciences

ABSTRACT. 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. For that it is necessary to make new building regulations. Consquently there is a big experimental testing ground over a vast territory of the world and high-rise buildings constructed there wait 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, the method that allows to estimate actual technical parameters of a building using experimental data of a building during wind loading, damping decrement, resonant frequencies, building behavior during any seismic wave passing through its foundation, is described. *© 2018 Bull. Georg. Natl. Acad. Sci.*

Key words: high-rise buildings, wind loading, 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 to high rise buildings."

"Formulation of principles of estimation of earthquake safety of high-rise buildings is not fully completed yet."

It obviously comes to mind that a polygon is being prepared over a vast area of the Earth's surface and high-rise buildings constructed there wait 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 stability of existing buildings. We also have publications on the subject [2]. In the present paper we propose an approach that considers that wind loading is one of the strongest impacts and analysis of building behavior during wind loading can provide reliable information for estimation of building behavior during earthquake impact.

Let us first consider the general case of two dynamical processes of building vibration. Fig. 1. shows simplified scheme of a building in which three design points are marked.

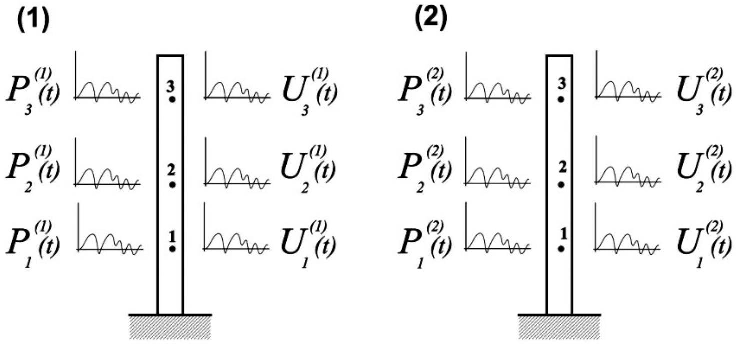

Fig. 1. Two dynamical processes of a building.

During the first dynamical process a construction is affected by external forces $P_i^{(1)}(t)$ that cause displacements $U_i^{(1)}(t)$. In the second state a construction is affected by other forces $P_i^{(2)}(t)$ that cause displacements $U_i^{(2)}(t)$.

The principle of reciprocity of these two processes says that the working of external forces of the first state on displacements of the second one is equal to the working of external forces of the second state on displacements of the first one. The principle can be formulated this way [3]:

$$\int_0^t P_i^{(1)}(\tau)\cdot U_i^{(2)}(t-\tau)d\tau = \int_0^t P_i^{(2)}(t-\tau)U_i^{(1)}(\tau)d\tau. \quad (1)$$

In discrete representation an integral equation (1) is equivalent to the system of linear algebraic equations set out in Fig. 2. Integral equation (1) and corresponding system of algebraic equations allow to determine actual behaviour of a building at different impacts. But let us get back to the issue considered in the present paper and focus on fluctuations of a building, when seismic wave $U_1^{(1)}(t)$ passes in its foundation in the point i=1.

Fig. 3 shows how seismic wave $U_1^{(1)}(t)$ passes the first point of a building. We are interested in fluctuations in the points $U_2^{(1)}(t)$ and $U_3^{(1)}(t)$.

To resolve this problem, we propose to use the behavior of a building during wind loadings that is shown in Fig.3.

In the second state a building is impacted by wind loadings $P_1^{(2)}(t)$, $P_2^{(2)}(t)$, $P_3^{(2)}(t)$ that cause fluctuations $U_1^{(2)}(t)$, $U_2^{(2)}(t)$, $U_3^{(2)}(t)$.

	τ=0			τ=1			τ=2			τ=3			
	$U_1^{(1)}(0)$	$U_2^{(1)}(0)$	$U_3^{(1)}(0)$	$U_1^{(1)}(1)$	$U_2^{(1)}(1)$	$U_3^{(1)}(1)$	$U_1^{(1)}(2)$	$U_2^{(1)}(2)$	$U_3^{(1)}(2)$	$U_1^{(1)}(3)$	$U_2^{(1)}(3)$	$U_3^{(1)}(3)$	
t=1	$P_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	$P_1^{(2)}(0)$	$P_2^{(2)}(0)$	$P_3^{(2)}(0)$							—
t=2	$P_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	$P_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	$P_1^{(2)}(0)$	$P_2^{(2)}(0)$	$P_3^{(2)}(0)$				—
t=3	$P_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	$P_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	$P_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	$P_1^{(2)}(0)$	$P_2^{(2)}(0)$	$P_3^{(2)}(0)$	—
t=4	$P_1^{(2)}(4)$	$P_2^{(2)}(4)$	$P_3^{(2)}(4)$	$P_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	$P_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	$P_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	—
t=5	$P_1^{(2)}(5)$	$P_2^{(2)}(5)$	$P_3^{(2)}(5)$	$P_1^{(2)}(4)$	$P_2^{(2)}(4)$	$P_3^{(2)}(4)$	$P_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	$P_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	—
t=6	$P_1^{(2)}(6)$	$P_2^{(2)}(6)$	$P_3^{(2)}(6)$	$P_1^{(2)}(5)$	$P_2^{(2)}(5)$	$P_3^{(2)}(5)$	$P_1^{(2)}(4)$	$P_2^{(2)}(4)$	$P_3^{(2)}(4)$	$P_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—

=

τ=0			τ=1			τ=2			τ=3			
$P_1^{(1)}(0)$	$P_2^{(1)}(0)$	$P_3^{(1)}(0)$	$P_1^{(1)}(1)$	$P_2^{(1)}(1)$	$P_3^{(1)}(1)$	$P_1^{(1)}(2)$	$P_2^{(1)}(2)$	$P_3^{(1)}(2)$	$P_1^{(1)}(3)$	$P_2^{(1)}(3)$	$P_3^{(1)}(3)$	
$U_1^{(2)}(1)$	$U_2^{(2)}(1)$	$U_3^{(2)}(1)$	$U_1^{(2)}(0)$	$U_2^{(2)}(0)$	$U_3^{(2)}(0)$							
$U_1^{(2)}(2)$	$U_2^{(2)}(2)$	$U_3^{(2)}(2)$	$U_1^{(2)}(1)$	$U_2^{(2)}(1)$	$U_3^{(2)}(1)$	$U_1^{(2)}(0)$	$U_2^{(2)}(0)$	$U_3^{(2)}(0)$				
$U_1^{(2)}(3)$	$U_2^{(2)}(3)$	$U_3^{(2)}(3)$	$U_1^{(2)}(2)$	$U_2^{(2)}(2)$	$U_3^{(2)}(2)$	$U_1^{(2)}(1)$	$U_2^{(2)}(1)$	$U_3^{(2)}(1)$	$U_1^{(2)}(0)$	$U_2^{(2)}(0)$	$U_3^{(2)}(0)$	—
$U_1^{(2}(4)$	$U_2^{(2)}(4)$	$U_3^{(2)}(4)$	$U_1^{(2)}(3)$	$U_2^{(2)}(3)$	$U_3^{(2)}(3)$	$U_1^{(2)}(2)$	$U_2^{(2)}(2)$	$U_3^{(2)}(2)$	$U_1^{(2)}(1)$	$U_2^{(2)}(1)$	$U_3^{(2)}(1)$	—
$U_1^{(2)}(5)$	$U_2^{(2)}(5)$	$U_3^{(2)}(5)$	$U_1^{(2)}(4)$	$U_2^{(2)}(4)$	$U_3^{(2)}(4)$	$U_1^{(2)}(3)$	$U_2^{(2)}(3)$	$U_3^{(2)}(3)$	$U_1^{(2)}(2)$	$U_2^{(2)}(2)$	$U_3^{(2)}(2)$	—
$U_1^{(2)}(6)$	$U_2^{(2)}(6)$	$U_3^{(2)}(6)$	$U_1^{(2)}(5)$	$U_2^{(2)}(5)$	$U_3^{(2)}(5)$	$U_1^{(2}(4)$	$U_2^{(2)}(4)$	$U_3^{(2)}(4)$	$U_1^{(2)}(3)$	$U_2^{(2)}(3)$	$U_3^{(2)}(3)$	—
—	—	—	—	—	—	—	—	—	—	—	—	—

Fig. 2. Algebraic equations for two dynamic processes.

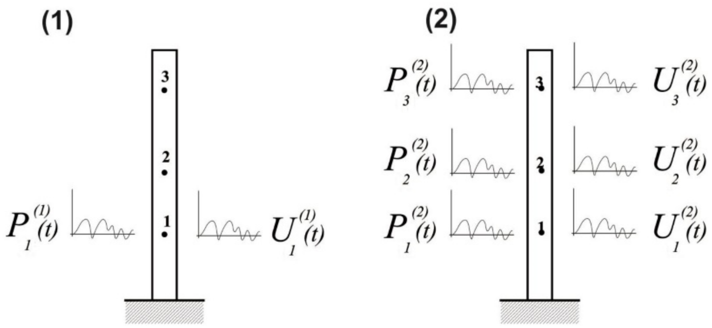

Fig. 3. Two dynamical processes of a building: 1) Earthquake load, 2) Wind load.

It is understood that in the second condition, i.e. during wind loadings wind loads $P_i^{(2)}(t)$ and displacements $U_i^{(2)}(t)$ are recorded in target points experimentally.

For the considered seismic problem an integral equation will be formulated this way:

$$\int_0^t P_1^{(1)}(\tau)\cdot U_1^{(2)}(t-\tau)d\tau = \int_0^t \Big[P_1^{(2)}(t-\tau)U_1^{(1)}\tau(d\tau) + P_2^{(2)}(t-\tau)U_2^{(1)}\tau(d\tau) + P_3^{(2)}(t)U_3^{(1)}(t)\Big]d\tau. \quad (2)$$

The system of linear algebraic equations transforms in the following way (Fig.4):

	$\tau=0$			$\tau=1$			$\tau=2$			$\tau=3$			
	$P_1^{(1)}(0)$	$U_2^{(1)}(0)$	$U_3^{(1)}(0)$	$P_1^{(1)}(1)$	$U_2^{(1)}(1)$	$U_3^{(1)}(1)$	$P_1^{(1)}(2)$	$U_2^{(1)}(2)$	$U_3^{(1)}(2)$	$P_1^{(1)}(3)$	$U_2^{(1)}(3)$	$U_3^{(1)}(3)$	–
t=1	$U_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	$U_1^{(2)}(0)$	$P_2^{(2)}(0)$	$P_3^{(2)}(0)$							–
t=2	$U_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	$U_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	$U_1^{(2)}(0)$	$P_2^{(2)}(0)$	$P_3^{(2)}(0)$				–
t=3	$U_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	$U_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	$U_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	$U_1^{(2)}(0)$	$P_2^{(2)}(0)$	$P_3^{(2)}(0)$	–
t=4	$U_1^{(2}(4)$	$P_2^{(2)}(4)$	$P_3^{(2)}(4)$	$U_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	$U_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	$U_1^{(2)}(1)$	$P_2^{(2)}(1)$	$P_3^{(2)}(1)$	–
t=5	$U_1^{(2)}(5)$	$P_2^{(2)}(5)$	$P_3^{(2)}(5)$	$U_1^{(2)}(4)$	$P_2^{(2)}(4)$	$P_3^{(2)}(4)$	$U_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	$U_1^{(2)}(2)$	$P_2^{(2)}(2)$	$P_3^{(2)}(2)$	–
t=6	$U_1^{(2)}(6)$	$P_2^{(2)}(6)$	$P_3^{(2)}(6)$	$U_1^{(2)}(5)$	$P_2^{(2)}(5)$	$P_3^{(2)}(5)$	$U_1^{(2}(4)$	$P_2^{(2)}(4)$	$P_3^{(2)}(4)$	$U_1^{(2)}(3)$	$P_2^{(2)}(3)$	$P_3^{(2)}(3)$	–
	–	–	–	–	–	–	–	–	–	–	–	–	–

=

$U_1^{(1)}(0)$	$U_1^{(1)}(1)$	$U_1^{(1)}(2)$	$U_1^{(1)}(3)$	–
$P_1^{(2)}(1)$	$P_1^{(2)}(0)$			–
$P_1^{(2)}(2)$	$P_1^{(2)}(1)$	$P_1^{(2)}(0)$		–
$P_1^{(2)}(3)$	$P_1^{(2)}(2)$	$P_1^{(2)}(1)$	$P_1^{(2)}(0)$	–
$P_1^{(2)}(4)$	$P_1^{(2)}(3)$	$P_1^{(2)}(2)$	$P_1^{(2)}(1)$	–
$P_1^{(2)}(5)$	$P_1^{(2)}(4)$	$P_1^{(2)}(3)$	$P_1^{(2)}(2)$	–
$P_1^{(2)}(6)$	$P_1^{(2)}(5)$	$P_1^{(2)}(4)$	$P_1^{(2)}(3)$	–
–	–	–	–	–

Fig. 4. Algebraic equations for seismic load.

Conclusion

In recent years, high-rise constructions are intensively conducted in seismically active areas worldwide (US, Canada, Japan, Chili, Europe, etc.) that is accompanied by the development of the respective regulatory framework. According to authoritative experts, it is not appropriate for high-rise buildings to use current regulatory requirements that are based on the summarized experience of the seismic behavior of low-rise buildings during seismic loading. According to them, principles of seismic safety of high-rise buildings have not been conclusively formulated yet. For that it is necessary to make new building regulations.

According to the authorities, there is a big experimental testing ground over a vast territory of the world and high-rise buildings constructed there wait for experimental testing during real earthquakes.

The necessity of testing of the seismic stability of high-rise buildings experimentally without awaiting testing by a real earthquake comes to the fore in the described situation.

In the paper the method that allows to estimate actual technical parameters of a building using experimental data of a building during wind loading, damping decrement, resonant frequencies, building behavior during any seismic wave passing through its foundation, is described.

სამშენებლო მექანიკა

ქარის ზემოქმედებისას მაღლივი შენობის ქცევის ექსპერიმენტული მონაცემების დამუშავების საფუძველზე შენობის ქცევის შესწავლა მის ფუძეში ნებისმიერი სეისმური ტალღის გავლისას

გ. გაბრიჩიძე

აკადემიის წევრი, ბუნებრივი კატასტროფების სამეცნიერო პრობლემების შემსწავლელი კომისია.

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 აქტუალობას ხდება მოსაზრება, რომ არ დაველოდოთ მიწისძვრებს და არსებული მაღლივი შენობების ქცევა მიწისძვრისას შევაფასოთ ექსპერიმენტული გზით. ამ მიზანს ემსახურება სტატიაში შემოთავაზებული მიდგომა.

REFERENCES

1. Nemchinov Y.I. (2015) Seismostoikost visotnikh zdanii i soorujenii. Kiev, (583), (in Russian).
2. Gabrichidze G. (2012) One Mathematical Model and Algorithm of the. Microtremor Use for Structure Real Seismic Resource Assessment. *Bull. Georg. Natl. Acad. Sci.* 6, № 2, 39-42.
3. Nowacki W. (1975) Teoriia uprugosti. Moskva (in Russian).

Received June, 2018