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Structural Mechanics

Does Modern Ideology of Earthquake Engineering Ensure the Declared Levels of Damage of Structures at Earthquakes?

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ABSTRACT. The basic position of the modern ideology of earthquake engineering is based on the idea that a structure should be designed so that it suffers almost no damage at an earthquake, the occurrence of which is most probable in the given area during the lifetime of the structure. This statement is essentially based on the so-called Performance Based Design, the ideology of the 21st century. In the article attention is focused on the fact that the modern ideology of earthquake engineering assigns structures to a dangerous zone in which their behavior is defined by processes of damage and destruction of materials, which is a nonequilibrium process and demands application of special refined methods of research. In such conditions use of ratios that correspond to static conditions of loading to describe the process of damage of materials appears to be unfounded. The article raises the question of the necessity of working out a new mathematical model of behavior of materials and structures at rapid intensive impacts. *© 2011 Bull. Georg. Natl. Acad. Sci.*

Key words*: performance based design, nonequilibrium processes, dangerous zone, unprotected structures.*

Earthquake has always been a familiar phenomenon to mankind. First humans lived, to use modern terminology, in seismoactive zones and tried to protect themselves somehow from this insidious natural phenomenon. As to the ideology of earthquake engineering, for its beginning one may accept the last third of the 19th century and to single out some important stages of its development, the last of which is presented schematically below.

In this Table [1], the so-called Performance Based Design, named the ideology of the 21st century [2], is presented. It rests on the position which was formulated already at the initial stages of development of the ideology

Table

The scheme of Performance Based Design [1]

	Fully operational	Operational	Life safe	Near collapse
Frequent	▲			
Occasional	▼	▲		
Rare	•	▼	▲	
Very rare		•	▼	▲

▲ Basic facilities; ▼ Essential or hazardous facilities; • Critical facilities.

Unacceptable performance

of earthquake engineering and which states the following.

In seismically active regions weak earthquakes occur more often than strong ones, therefore, the structure should be designed so that it remains standing almost without damage at a weak earthquake which, taking into account the seismic activity of the territory of construction, is the most probable to occur during the period of operation of the structure. At stronger earthquakes, whose probability of occurrence is less than a weak one, the structure should receive damage of various degrees. All this is seen well in the above scheme where the intensity range of earthquakes is divided into four parts and accordingly, in the four parts the range of the condition of a structure is presented, beginning from the intact condition to a condition close to collapse. Let us pay attention to one important circumstance - except weak earthquakes, at all stronger earthquakes, it is required that a different damage rate in a pise in the structure! It may be said that the modern ideology of earthquake engineering not only does not try to keep the structure away from a dangerous zone, where it can receive damage, but on the contrary, it tries to locate the building in this zone and demands that the structure rationally use its resources and in such way resist destructive impact of the earthquake.

The reality dictates an absolutely different situation. At the impact of seismic waves the behavior of a structure is predetermined by processes of damage and destruction of the material of the structure, which are subject to complex nonlinear laws belonging to nonequilibrium processes of thermodynamics. What are the laws of nonlinear mechanics, especially at strong nonlinearity, which operate at destruction of materials, are well known to all. I shall only quote an extract from the monograph [3], one of whose authors, I. Prigozhin has been awarded the Nobel Prize for researches in the field of nonequilibrium processes of thermodynamics:

"A special place in our analysis is given to the sudden occurrence of chaotic dynamics – a natural tendency of a wide class of systems in transition to conditions in which both deterministic and unpredictable behavior are revealed".

Now we shall see what means modern ideology of earthquake engineering uses to forecast the differentiated levels of damage of structures at earthquakes. We shall focus attention on one main question - on methods of designing structures. Modern building codes [4] and software packages offer several methods of designing structures:

- Spectral method with its modifications,
- Non-linear time-history analysis; the solution of systems of nonlinear differential equations with account of time (so-called step-by-step methods),
- Non-linear static (pushover) analysis. A conditional static method – so-called Pushover Design Method.

These algorithms are realized in modern powerful program systems such, as ANSYS, DYNA3D [5] and others. As said above, complexity of establishing the picture of damage and destruction of structures determines the properties of the material of the structure, in particular nonlinear dependences between stresses and deformations (rheological ratios). In modern softwear packages more than 200 models of such ratios are given and it would seem there is a big possibility of choice among them, but all of them give the picture of behavior of the material at a static regime of external impact. They are used in designing some objects for dynamic, including seismic, impacts. A paradoxical situation! At seismic impact the structure is damaged, or even collapses over a short time interval (minutes), and studying of this fast process the model of damage of a material is used at slow static external influences.

Let us explain that, if deformations of material are small, the behavior of material at fast and slow conditions of loading qualitatively do not differ from each other. On the contrary, when material deformation is big, i.e. when we force a material to fall outside the limits of intact condition, then the pictures of behavior of the material at fast and slow conditions of loading qualitatively can differ from each other. For example, at slow loading creep and plasticity phenomena appear, and at fast loading they will have no time to manifest themselves. Moreover, at some types of deformation, the plasticity phenomena are not manifested even at slow loading. And at a complex combination of fast external influence, even it is mentally impossible to foresee the character of behavior of a material. Such complex combination of fast intensive stresses arises in structures at the influence of strong intensive seismic waves. In such complex dynamic conditions, prognostication of the levels of damage of structures on the basis of application of ratios characteristic of slow static conditions of loading, we define as discrepancy of external dynamic and local static mathematical models and we consider such position unjustified and even hazardous.

To all aforesaid it is necessary to add that seismic impact, i.e. character of seismic waves, their parameters, duration, frequency etc. can never be set with any satisfactory accuracy. How sensitive are the pictures of damage and destruction of different structures to small or big deviations of external rapid impact have not been studied either.

The aforementioned two circumstances make us give a negative answer to the question asked in the title of the

paper, namely that today's ideology of earthquake engineering does not possess sufficient arguments to state that it ensures reliability of forecasting of declared levels of damage of a structure at an earthquake. This question was repeatedly raised in our publications [6,7].

Such is the real situation in one of the important directions of human activity - in the field of building in active seismic regions of our planet. If we agree with the above assessment, it is necessary to stir up activity without delay in the direction of perfecting the existing, or creation of a new model of the process of damage and destruction of structure at fast, intensive, in particular seismic influences. One direction of such researches will without fail be connected with studying the processes of crack formation and destruction of materials on micro and mesoscale. The modern level of development of science gives the chance for such researches. Such studies are carried out, publications, conferences are held, there are interesting results and recommendations [8,9]. Against the background of such investigations attempts can be made on better ground at applying extreme principles of thermodynamics for the creation of new and assessment of the reliability of the existing engineering methods of calculation of structures to withstand strong, intensive influences.

სამშენებლო მექანიკა

უზრუნველყოფს თუ არა სეისმომედეგი მშენებლობის თანამედროვე კონცეფცია ნაგებობათა დაზიანების დეკლარირებულ დონეებს მიწისძვრისას

გ. გაბრიჩიძე

აკადემიის წევრი, კ. ზავრიევის სამშენებლო მექანიკის და სეისმომედეგობის ინსტიტუტი, თბილისი.

სეისმომედეგი პროექტირების თანამედროვე იდეოლოგიის საყრდენი პოზიცია მდგომარეობს იმაში, რომ ნაგებობა უნდა დაპროექტდეს ისე, რომ თითქმის დაუზიანებლად გაუძლოს ამ ტერიტორიის სეისმური რეჟიმისთვის დამახასიათებელ ყველაზე უფრო მოსალოდნელ ხშირ მიწისძვრას, ხოლო უფრო იშვიათი, ანუ უფრო ძლიერი მიწისძვრებისას, მიიღოს გარკვეული დონის სხვადასხვა ხარისხის დაზიანებები. ეს შეადგენს არსს ახალი, XXI საუკუნის იდეოლოგიისასაც, რომელსაც უწოდებენ Performance Based Design. წერილში ჩამოყალიბებულია მოსაზრება, რომ ამ იდეოლოგიას ნაგებობა შეჰყავს საშიშ ზონაში, რომელშიც მის ქცევას განსაზღვრავენ უწონასწორო ბუნების მქონე პროცესების კანონები. ეს მოითხოვს კვლევებს ფაქიზი მეთოდების გამოყენებით. ამ თვალსაზრისით, უხეშად შეიძლება მივიჩნიოთ თანამედროვე სეისმომედეგი პროექტირებისას გამოყენებული მიდგომა, როცა ნაგებობის დაზიანებისა და რღვევის დინამიკური პროცესების შესწავლისას გამოიყენებენ სამშენებლო მასალების დაზიანებისა და რღვევის მოდელს, რომელიც შეესაბამება მასალის ქცევას მასზე სტატიკური, ნელი დატვირთვების მოქმედებისას. ამ და სხვა გარემოებებზე მითითებით, წერილში გამოთქმულია მოსაზრება, რომ სეისმომედეგი პროექტირების თანამედროვე იდეოლოგია ვერ უზრუნველყოფს ნაგებობათა პროგნოზირებულ დაზიანებათა დიფერენცირებულ დონეებს მიწისძვრისას. დასმულია ახალი მიმართულებით კვლევების ჩატარების აუცილებლობის საკითხი.

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