DISCUSSION: Past, present, and future of nonlinear analysis for concrete structures

Koji Sakai
Professor of Kagawa University

Sakai:

Thank you all for gathering here today. We have invited three Japanese experts in nonlinear analysis for concrete structures who represent different generations: Tada-aki Tanabe(born in 1940), Koichi Maekawa(born in 1957), and Hikaru Nakamura (born in 1964). We are going to hear from them about the past course of development of this field as well as its future prospects.

Milestones in research activities

Sakai:

First of all, I would like to ask each of you to talk about the milestones in your research activities.

Tanabe:

Tada-aki Tanabe
Emeritus Professor of Nagoya University

In 1971, I began developing analytical techniques for the problems of heat and creep in relation to the design of nuclear power plants. Regarding exchange with foreign countries, in 1984 there was a Japan-U.S. seminar concerning the finite element method, which was a very significant event for me. That was the first time I heard about concepts such as localization, fracture, and nonlocal theory, and it had quite an impact on me. I realized that it was necessary to consider very fundamental aspects.

Koichi Maekawa
Professor of The University of Tokyo

Maekawa:

When I was a second-year student of a master course, I participated in the IABSE Colloquium which was held in Delft in 1981 and found it quite inspiring. At that colloquium, I was led to think about the approach to experimentation, rather than the content of nonlinear analysis. One well-known professor gave a talk and confessed that he had performed an experiment in the past with inadequate boundary conditions. I was moved by the professor's humility, and I also recognized that progress, of course, occurs in experimentation, just as advances are made in the area of analysis as well. Since then, I have always made sure in my research to combine experimental verification with numerical analysis.

Nakamura:

I visited the University of Tokyo when I was a second-year master's student, and I was asked a question by Prof. Maekawa, “why is analysis necessary?” At that time, I was unable to come up with an answer to that question. Professor Maekawa explained that because an experiment is conducted within a certain scope, the conclusions from the experiment only apply within that scope. However, we actually need to obtain information that goes beyond that experimental scope, and analysis is the method that enables us to do so. That was the first time I understood the true significance of numerical analysis.

Hikaru Nakamura
Professor of Nagoya University

Maekawa:

At that time, I was asking myself about the significance of numerical analysis. I thought that it would be impossible to understand the extremes without a logical framework.

In fact**,** Prof. Tanabe's work was one of the factors that led me to analytical research. When I was a first-year master's student, Prof. Tanabe was studying the problem of cracking due to thermal stress with deformation analysis using a shell element in relation to nuclear power plants. I seemed to glimpse the future in Prof. Tanabe's work, and I then decided to go into the field of analysis.

Nonlinear analysis in relation to practical works

Sakai:

The early 1980s was an important era, including the Japan-U.S. seminars, IABSE colloquia, and so on. It also seems that a great deal of positive motivation was conveyed between generations.

Please tell me a little more about your research concerning nuclear power plants.

Tanabe:

I got my PhD degree in 1971, and at that time, Japan was just beginning to build nuclear power plants here and there. Because nuclear power plants are made out of concrete, it was necessary to deal with the problem of thermal stress and the problem of creep. However, we did not have the tools at that time to do that. Therefore, I myself created a thermal stress analysis program using the axisymmetric finite element method. If cracking occurs in the base mat of a nuclear power plant just after placing, there is a risk that nuclear material could be dispersed from the nuclear reactor. Therefore, there is a design condition stating that absolutely no thermal cracking can occur in the base mat. I performed a great deal of analysis and compared the results with the experiments.

Maekawa:

Professor Tanabe, I find it highly significant that you tackled the issue of thermal stress head-on, including the aspects of structural shape and boundary conditions. I think that heat is the issue, which is best suited for using the finite element method. Today, as the amount of heat released by cement hydration is on the rise, early-age cracking due to thermal stress has become a problem in many structures. Currently in Japan, nonlinear analysis is used for the issue of cracking in practical applications.

Tanabe:

For quite a long time, there has been a high level of demand in Japan for controlling crack width. For some reason, this has been a concern not only among engineers but also among the general public.

Maekawa:

When there is a need in society, technologies are developed through research, and those technologies are then put into practical use. The technologies are assessed in practical terms, and the results of that assessment provide feedback that leads to further advances in research. The issue of thermal stress cracking is a good example of how this cycle can function.

Tanabe:

I agree. And in addition, I think that advanced technologies would not be developed if the need did not exist to build structures that are extremely challenging in practical terms, such as nuclear power plants.

Sakai:

In relation to actual events, I think that the assessment of structural damage due to the 1995 Great Hanshin-Awaji Earthquake has had an important effect on the development of nonlinear analysis. What are your thoughts on that?

Maekawa:

The use of nonlinear analysis for earthquake resistance goes back to the 1970s in the area of nuclear power. For buildings, ground-structure interaction dynamic nonlinear analysis was used, based on a very simple lumped mass model. The electric power industry was the source of momentum toward the application of two-dimensional nonlinear finite element analysis in the practical design of underground structures for nuclear power plants. Their technological development proved very helpful at the time of that great earthquake.

Nakamura:

I think that the analytical technologies themselves already existed. Some individual technologies have become more advanced since the earthquake, but the earthquake was also the impetus that led to a large increase in the use of those technologies in practical works. Today, nonlinear dynamic analysis is used in the design of practically almost all structures, and this technology seems to have come into general use. I think this is an example of research and practical works coming together in response to the needs of society, in which the result was to accelerate the progress of nonlinear analysis technology.

Maekawa:

In Japan, nonlinear analysis has clearly become part of the world of practical works. I believe that this reflects the strength of Japan's analytical technology.

Mechanical models for nonlinear analysis

Sakai:

What are the important mechanical models for nonlinear analysis, in your opinions?

Tanabe:

I think we need to pay more attention to shear transfer models for concrete. This also includes the problem of dilatancy, but I think that it is impossible to properly perform a dynamic alternate load simulation unless the model can express the shear behavior of crack surface.

Maekawa:

I feel the same way. Shear transfer can also be handled with a simple method based on rotating cracks, but that has its limits. Shear transfer plays a very important supporting role, although it is not the main actor; and as in the case of problems for earthquake resistance such as the occurrence of cracks in various directions, I do not think that it is feasible to use simple me thods to deal with problems in which there is damage due to heat or cracking due to corrosion, and there are forces acting at the same time.

Nakamura:

I think that an important factor for the successful handling in continuum mechanics of a brittle material such as concrete was the systematic establishment of the **smeared** constitutive law. This has made it possible to generally solve many concrete structures. Another important event after that was the introduction of the concept of fracture mechanics. This has made it possible to solve the shear failures and post-peak behaviors. I think that the concept of fracture mechanics now plays a very important role in the analysis of fracture behavior during an earthquake, as well.

Maekawa:

I think that ultimately, in the world of engineering, concrete is the area that has been the greatest beneficiary of nonlinear fracture mechanics.

Conditions for introduction of advanced technologies

Sakai:

Moving to a different subject, what do you see as the conditions for introduction of advanced technologies?

Tanabe:

I think that this has happened with some technical delay in the case of nuclear power plants. In the area of concrete buildings, building experts used dynamic nonlinear analysis with a lumped mass model, while different groups were handling underground structures. Since the technology was developed later for underground structures, it was possible to apply various new technologies. I think there is a tendency that the more effectively a technology has been applied in some area, the harder it becomes to abandon that technology later on.

Sakai:

At present, the concept of sustainability is becoming increasingly important in the construction field. There is some debate as to whether the existing design system itself poses an obstacle to the introduction of sustainability.

Maekawa:

I agree that it is easier to introduce advanced technologies when this happens at a later time. However, this is not always the case. Naturally, there is also some opposition to new things. People who have been using existing technologies often contend that it would not be reasonable to introduce new technologies. At such times, I think that the people involved are an important factor. I think that technological development is accelerated when there are people who have willpower as well as a technological background.

The future of nonlinear analysis

Sakai:

I would like to hear your thoughts on the future of nonlinear analysis.

Tanabe:

Computers have become extremely powerful. By using the distinct element method to dynamically solve equations of motion, we can now analyze sloshing problems, or even analyze blood flow after the rupture of a blood vessel. I think that our analytical methods will be transformed if computers become, for example, ten times as powerful as they are today. I think that continuum mechanics, which forms the basis of the finite element method, is a mathematically beautiful and refined method. When computers become more powerful, I think that techniques such as using the distinct element method to directly solve individual, multidimensional equations of motion by the hundreds of millions will be applied in the area of concrete. I think that progress in numerical analysis will be parallel to progress in computer technology.

Maekawa:

I agree, absolutely. Also, we will have more options if the tool environment changes drastically, so we'd be happy about that, and I think we would be able to embark on new endeavors as a result. I think that the role of academicians at universities is to do research and development which anticipates such advances. The distinct element method only becomes meaningful when dealing with a matrix of a rather large size; and thirty years ago, that would have been impossible. It is important not to limit one's own options by holding fast to a particular analytical method.

Nakamura:

The finite element method has been used with a great deal of success, and I think that some people may now consider it to be an all-purpose tool. However, if we take that attitude, development could come to a halt. Whenever you come up against some kind of obstacle, it's important to think about whether you can use the existing methods to overcome it, or whether it can be overcome with a new method.

Expectations for future generations

Sakai:

What kind of message would you each like to communicate from your own generation to future generations?

Tanabe:

Although Prof. Maekawa is of a younger generation, I have a great deal of respect for him, as he has broken new ground in a variety of aspects. I hope that Prof. Maekawa will take the lead in steadily advancing the kinds of work that will be important for the future of Japan and the rest of the world. In relation to practical operations, I think there are many things that only Japan can do. With hard work by young people, I have great expectations that nonlinear analysis will continue to develop more and more.

Maekawa:

I think it is important for young people to have strong willpower. If you have strong willpower, that can lead to dynamic development. In the area of concrete, there aren't many people who take the attitude of "that's not my job." We keep looking forward, and even when a difficult problem occurred, we have conducted research and overcome the problem. I myself am interested in the aspect of ground, for one thing; and I would like to expand my scope of research a little more in that area as well.

Nakamura:

I think that it's important to consider the purpose for using nonlinear analysis. I think scientists have the desire to solve highly multidimensional equations and to create primitive laws, based on the distinct element method, and then to solve things just as they are, based on those laws alone.

Meanwhile, considering the future development of nonlinear analysis, it is doubtful whether nonlinear analysis ought to be used in the same way that it is being used now. Advanced analytical techniques can provide high-resolution indicators for engineering, and it will become possible to design more rational structures using those indicators. I think that the developers of analytical techniques should work on satisfying both their own desires and the demands of engineering.

Sakai:

Thank you.