GEOASIA Bulletin No.15

ALL SOILS ALL STATES ALL ROUND
GEO-*A*NALY*S*IS *I*NTEGR*A*TION

For finding soil deformation and collapse in sandy, intermediate and clayey soils, and for static or dynamic interests

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Edited by GEOASIA Research Society Office

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Message from the Society President

With the Covid-19 pandemic growing worse all the time and health services in some larger cities coming close to breakdown point, we now find ourselves confronted in Sapporo, where the Olympic marathon is due to be held, with summer temperatures higher than any recorded in the past hundred years. This 2021 Annual General Meeting of the GEOASIA Research Society has also been switched to online mode again, but I trust that all of our members are still as active in their research as ever.

In June, I received a request from the Chubu Geological Surveys Association to create a brief review guide that would be of value to engineers currently working in geological surveys and soil experiments. Being vanity-prone, I readily accepted this task, but when I actually got down to writing it, I came to see – not for the first time – how my faculties have gone down with age. As regards the guide, I was saved by the requirement that it should be "brief." But this also serves as a timely reminder to me of some of my own repeated appeals in this column up until three years ago about the need for a “GEOASIA textbook.”.

The theory of plasticity in geomechanics was originally adopted from the plasticity of metals. Geomechanics could never have existed without the von Mises criterion, The plasticity of metals had its own ample field for development in plastic processing, but in soil mechanics, much hard thought was needed before the two soil properties of compaction and induced anisotropy, neither of which exists in metals, could be worked into a theory of elastoplastic geomechanics. This may sound like an ordinary enough field designation, the kind of name found everywhere, but in fact, even for me, this is my first ever use of this term “elastoplastic geomechanics.”

Except under conditions of heat change, there are no other building materials – no metals, for example – that undergo compaction under the kinds of forces met with in civil engineering. Water is no exception. The behavior of soil compaction is the result of soil being a mixed body, combined out of earth, water and air. The property of “consistency” often attributed to clay soils similarly depends on it being viewed as a mixture, a mixture of earth and water. Sand, too – it hardly needs saying – will compact quite densely when dry with nothing but a few light taps. Moving on to induced anisotropy, this is another mode of behavior, like compaction, that is unknown in other materials. Why should this be? It is obvious that a clay soil should display anisotropic behavior, but visualizing the way sand is made up of discrete granules, clarification comes in a flash. Compared to the kinematic hardening in metals, which is much more of an ad hoc adjustment to circumstances, induced anisotropy in soils has its origin in their grain structure and can just as convincingly indicate and account for the phenomenon of re-liquefaction.

All of this hangs on the concept of the soil skeleton. The discovery of this notion, which made it possible to overcome the early limitations of the Cam clay model of elastoplastic mechanics for remolded clay, was of vital significance in this field. But even before that breakthrough, if one stops to think, it was already plain that metals and soils were essentially different.

Once I get going on this topic, there is no end to it. As a more practical indication of what might be wanted in a six-part GEOASIA coursebook, let me offer a few ideas, offered from the aging head of Asaoka rather than proposed from a platform.

A 6-part GEOASIA Learning Course

1 Elastoplastic Geomechanics 1
The mechanism of soil compaction,
Beyond $e - \log p'$

2 Elastoplastic Geomechanics 2
The one truth of soil is anisotropy!
The anisotropy of clay, Liquefaction (and re-liquefaction) of sand

3 Elastoplastic Geomechanics 3
Unsaturated soils, Ultimate states of soil mixtures

4 Computational Geotechnology 1
Equations of motion in a continuum, Finite variable analysis,
Calculations of interaction in a mixed body

5 Computational Geotechnology 2
Where solids and fluids meet, State-of-the-art computational geotechnology

6 GEOASIA in Geotechnology
No need for computation in geotechnology?
Using the GEOASIA program, Analysis guidance using latest case examples

Speaking from my experience as a not-so-young retiree, who still managed to put together an easy-to-digest outline for Part 1 in under ten days, an active team member assigned with a task of this size ought to be able to finish in five or six weekends, I would think, without the load interfering too badly with research and administrative routine. I hope at any rate that this sketch of a plan may help to restore a little momentum again to this stalled project.

Let me leave you with a light-hearted Chinese-style verse message in 4 x 7 measure:

読尽詩書五六担	Weighed down with years of learning,
老来方得一青衫	But I've earned my cap and gown.
佳人問我年多少	"Not so young now?" you ask me.
五十年前二十三	"Fifty years back? Twenty-three!"

To tell the truth, I've since turned twenty-four – fifty years back, of course.

Akira Asaoka

Senior research advisor, the Association for the Development of Earthquake Protection (reg. foundation)

Emeritus professor, Nagoya University

Research Results in 2020

(1) Combined external force effects of an earthquake and high water on the mechanical behavior of a river levee

Assuming a situation in which a river levee is subject to a combination of external forces – an earthquake coming on top of high water following heavy rain –, the purpose of this study was to use the soil-water-air coupled analysis program GEOASIA to investigate the additional effects that the raised river level and the soil saturation degree would have on the earthquake response of the structure. Figure 1 shows distributions of soil saturation degrees in the levee, along with the initial and risen water levels, just prior to the earthquake. If CASE 0 is taken as the zero situation, with no rise in the river, CASE 1 shows a result when the earthquake wave is assumed to strike just after the water level rises. In CASE 2, it strikes later, after soil saturation has spread and become steady. CASE 3 corresponds to CASE 1, and CASE 4 to CASE 2, for cases where the earthquake is assumed to strike later still, after the river has returned to its initial level. For the same five cases, Figure 2 shows shear strain distributions just after the earthquake. Comparing CASES 1 and 2 with CASE 0, first, it can be seen that the presence of more water at a higher level in the river has a considerable deforming effect on the landside area. That is because this river-facing flank is exposed to the earthquake in a state in which it is already affected by surface forces caused by the water level. Naturally, this side of the levee shows more deformation. In CASES 3 and 4, where the river level has subsided again before the earthquake, this kind of large deformation does not appear. But observing the differences due to soil saturation – that is, comparing CASE 2 with CASE 1, and CASE 4 with CASE 3 –, it is clear that CASES 2 and 4 show a weaker soil skeleton response to the earthquake overall, so that these two cases have a greater vulnerability to shear deformation. Summing up both points together, the deformation resistance of a river levee depends not only on the response offered against water seepage leading to soil saturation, but also on the stoutness of the defense against lateral surface pressure from the river at times of high water.

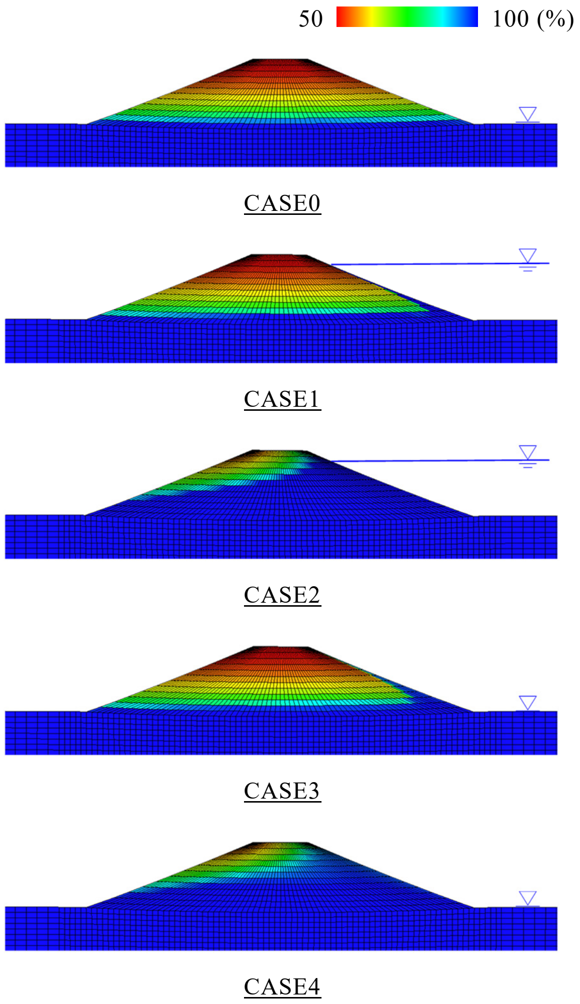


Fig. 1 Soil saturation degrees immediately before earthquake and river water levels

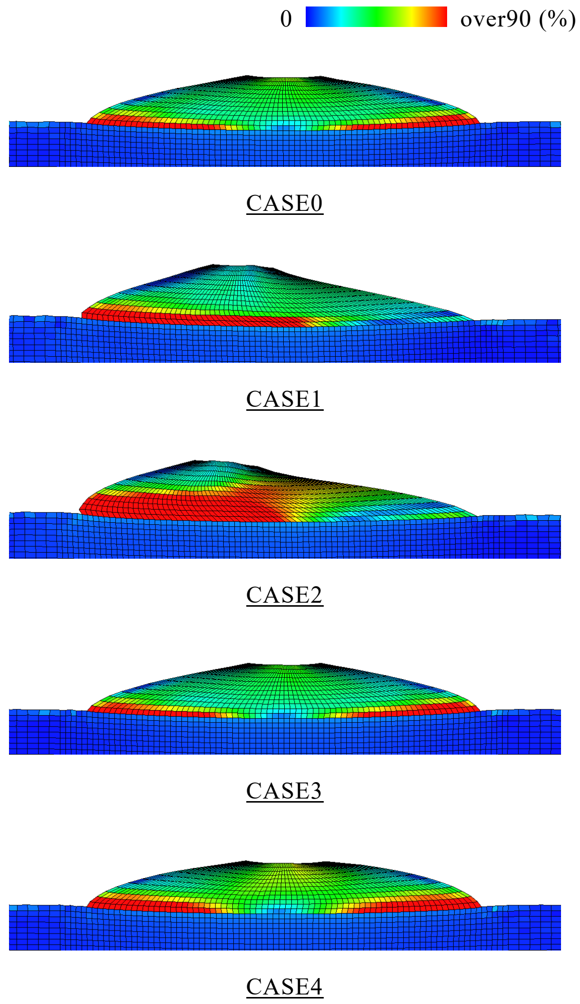
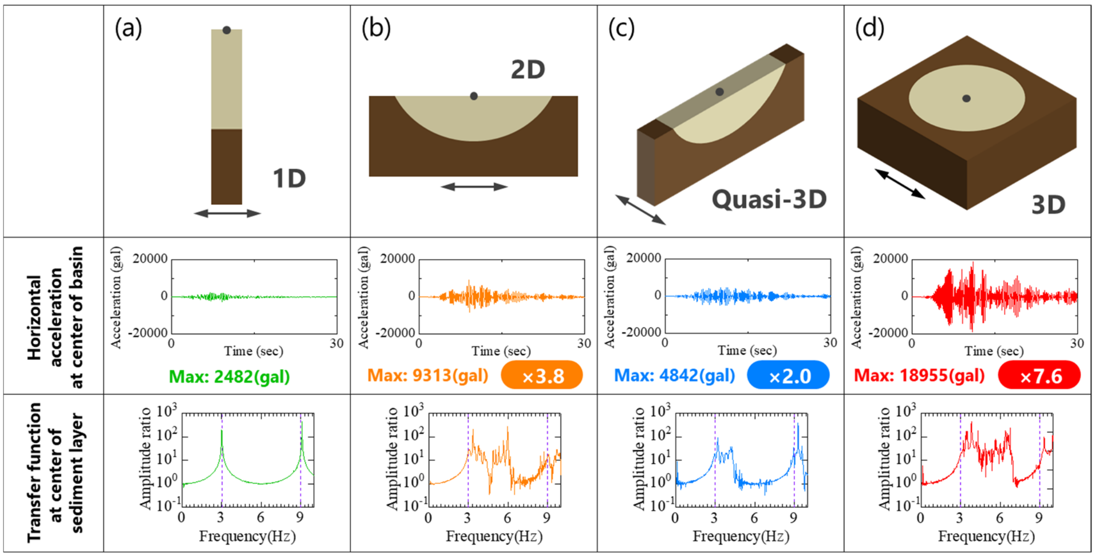


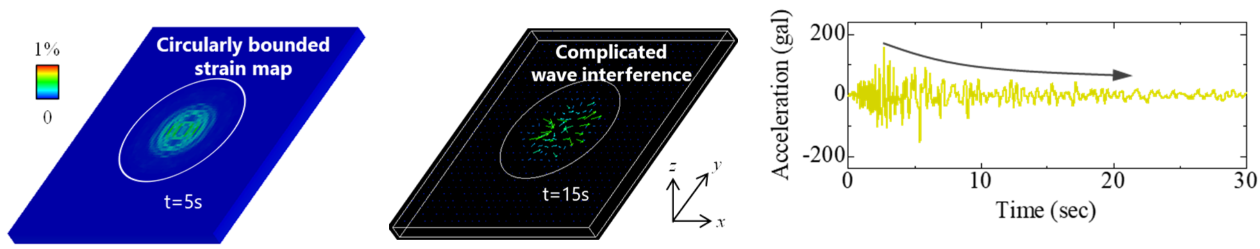
Fig. 2 Shear strain distributions just after earthquake

(2) 3-D analysis of the elastic/ elastoplastic earthquake response of a basin-shaped subsurface structure of sedimented material

A notoriously difficult issue in earthquake research is the response of a foundation that has a subsurface structure of unevenly sedimented material. An earthquake in circumstances like these is likely to produce either a strong local surface tremor or a succession of tremors that continue over a long period, in either case with considerable damage. The purpose of this research was to obtain a 3-D analysis of earthquake response in a spherical basin-shaped subsurface structure of the kind shown conceptually in Table 1(d). If the soil material is visualized as a one-phase elastic body, this 3-D analysis will generate the circularly bounded shear strain distribution and complicated wave interference diagrams shown in Table 1(d). Compared with the lower-dimension analyses 1(a-c), the surface acceleration is much higher and the frequency spectrum is also quite different. Hence the importance of the full 3-D analysis. As a next step, the material was subjected to another analysis of the same kind, visualized this time as a two-phase elastoplastic body. Assuming a foundation of loose sand, the result shown in Figure 4 was obtained: A fall in mean effective stress in the sediment layer as a whole (liquefaction) was accompanied by a flow motion ("sloshing"). As liquefaction halted the seismic wave in its progress, the surface acceleration declined as shown in Figure 5(a) and with the passage of time the transfer function in the sediment layer also reverted to a value less than 1 (Figure 5(b)). Alternatively, if a foundation material of soft clay is assumed, a different result of extreme wave amplification and prolongation in time is obtained. Clearly, therefore, that the response will differ considerably depending on the nature of the soil in the subsurface basin.

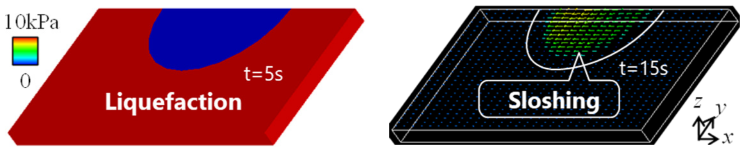
Table 1 Analysis conditions and results (elastic analysis)





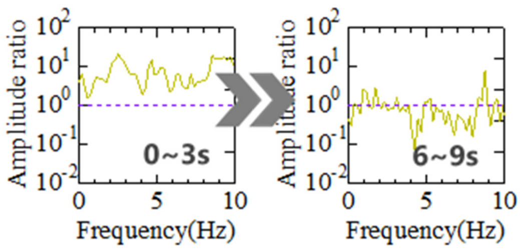
(a) Shear strain distributions (b)Displacement velocity field (a)Horizontal acceleration at surface

Fig. 3 1-phase elasticity analysis



(a)Mean effective stress distributions (b)Displacement velocity field

Fig. 4 2-phase elastoplasticity analysis (loose sand foundation)



(b)Variation in transfer function in sediment layer

Fig. 5 Acceleration wave form and transfer function (Loose sand foundation

(3) Simulation of re-liquefaction taking account of previous liquefaction history as a guide to the development of anisotropy

In sandy foundation soils, there are sometimes cases of liquefaction reoccurring at sites that have a past history of liquefaction due to earthquakes. This phenomenon is called “re-liquefaction” and 85 instances were confirmed following the Great East Japan Earthquake of 2011. The research reported here focused on the stress-induced development of anisotropy in the build-up to liquefaction and used the GEOASIA tool armed with a constitutive equation for composite load elastoplasticity to obtain a simulation of a re-liquefaction event. Figure 6 shows distributions of excess pore water pressure, and from this it can be seen that the soil with the past history of liquefaction succumbs while the soil no such history remains intact. The reason is because the property of anisotropy that developed in the course of the previous liquefaction remains with the soil after that event comes to an end. Looking at the shear strain values in Figure 7, the soil with the past liquefaction history shows values of around β_{12} = 0.5, indicating that the anisotropy state still persists. Consequently, when shearing occurs in a direction that permits a return of shear stress τ from minus toward plus, this sets off a sharp fall in the mean effective stress which results in liquefaction.

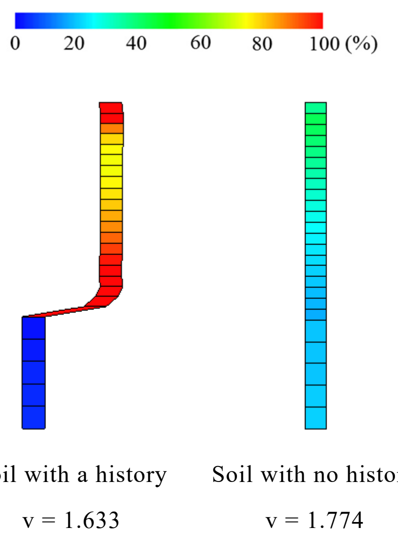


Fig.6 Excess pore water pressure distributions just after an earthquake

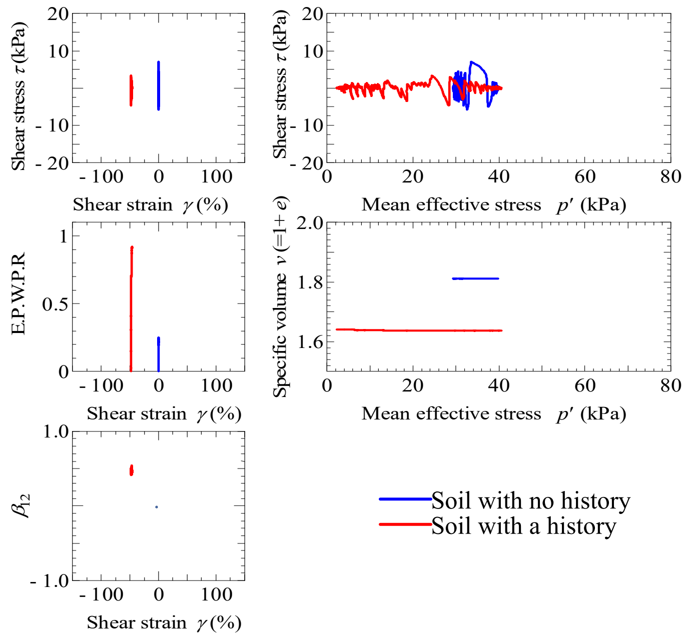


Fig. 7 Behaviors appearing in re-liquefaction factors

(4) Analysis of a process of imbrication and décollement (i.e., basal detachment) in a thrust fault zone under the action of uniform compression

When a ground is subjected to horizontal compression from one side, the resulting force combination may cause blocks of rock caught between the conflicting forces to "pop up," creating parallel lines of thrust faults "imbrication" and horizontal faults, i.e., décollement (basal detachment). In this research, a simulation of this formation process was undertaken using the GEOASIA program to supply the elastoplastic

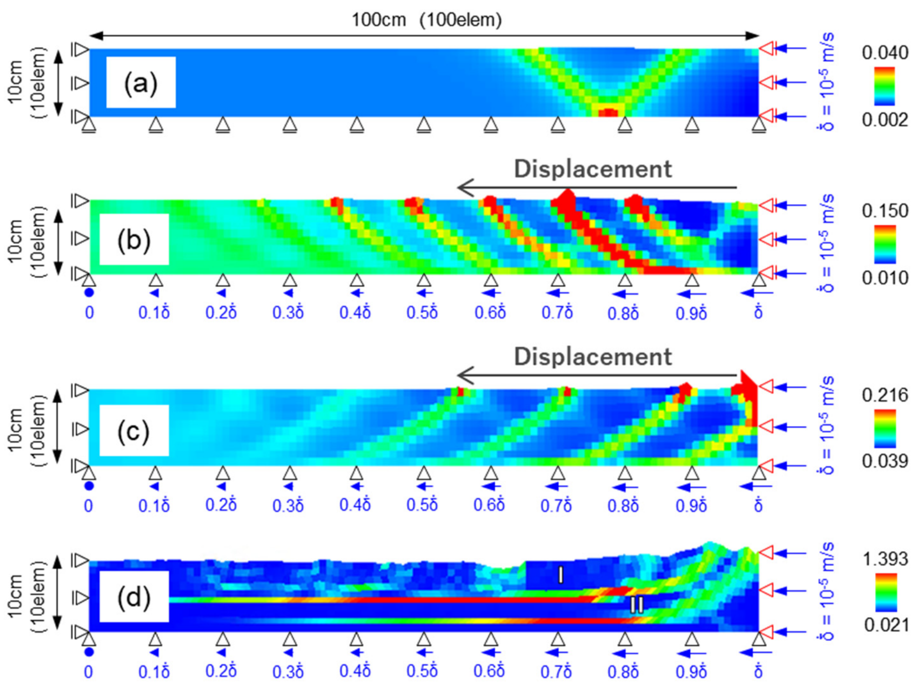


Fig. 8 Analysis of a process of imbrication and décollement (basal detachment)

deformation analysis. First, if the ground is viewed as a single-phase system in which an overconsolidated soil is subjected to horizontal compression, as just mentioned, a result of the kind shown in Figure 8(a) is obtained. Assuming no friction at the bottom surface, a pop-up effect is generated. But if a uniform compressive force continues to act horizontally on the entire bottom surface, as in Figure 8(b), a "piggy-back" formative process will develop in which a series of new thrust faults go on forming in turn from under the preceding ones. This formation in rows or series is what is called "imbrication." If we now also take account of the action of friction at the right-hand surface, as in Figure 8(c), the advancing thrust fault at the top of the ground will develop an "overstep" thrust order pattern which is found to vary greatly in appearance – for example with respect to the interval length between thrusts, etc. – depending on the boundary conditions. Looking last at Figure 8(d) which shows the result of a two-phase analysis for a soil material assumed to consist of semi-solidified sedimentary rock, a process of basal detachment décollement can be seen to have begun. Near the center of the model, a zone marked "I" has detached itself from the imbrication structure. Beneath this first slippage, a second décollement has also occurred in the zone marked" II". Finally, on a higher plane above these two zones of detachment, another feature of interest is the line of an earth tremor that has occurred in response to positive excess pore water pressure and strain localization.

Principal publications etc. in Academic Year 2020 (April 2020 – March 2021)

Academic papers:

【Soils and Foundations】

1. Triaxial test on water absorption compression of unsaturated soil and its soil-water-air-coupled elastoplastic finite deformation analysis, Soils and Foundations, Vol.60, No.5, pp.1151-1170, 2020.

【GEOMATE】

1. Progressive failure of unsaturated fill slope caused by cumulative damage under seepage surface, International Journal of GEOMATE, Vol. 20, Issue 78, pp. 1-8, 2021.

【Journal of Japan Society of Civil Engineers A2】

1. Reduction effects of liquefaction damage using small scale floating grid-type improvement for existing small scale structure. Vol. 75, No. 2, pp. I_329_I_339, 2020.
2. Influence of neighboring houses on liquefaction damage of detached houses. Vol. 75, No. 2, pp. I_401_I_410, 2020.
3. Soil-water-air coupled finite deformation simulation of model test on seepage failure of levee. Vol. 75, No. 2, pp.I_379_I_388, 2020.

International conferences:

【17th World Conference on Earthquake Engineering(Sendai, Japan) 】

1. Seismic damage of soft clay layer directly under the river levee that becomes prominent by L2 earthquake, 17th World Conference on Earthquake Engineering, 4b-0040, 2020.
2. Numerical analysis on aftershock-induced liquefaction of sandy ground with water-level raised by main shock, 17th World Conference on Earthquake Engineering, 4b-0051, 2020.
3. Localized/enormous seismic damage of subsurface ground induced by the stratum irregularity, 17th World Conference on Earthquake Engineering, 1d-0092, 2020.

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Domestic conferences:

【25th Conference of the Japan Society for Computational Engineering and Science (JSCES), June 2020)】 1 paper

【55th Japan National Conference on Geotechnical Engineering (July 2020)】 12 papers

【32nd Chubu Geotechnical Symposium (August 2020)】 3 papers

【75th Japan Society of Civil Engineers Annual Meeting (September 2020)】 3 papers

【Japan Society of Civil Engineers Chubu Chapter Conference (March 2021)】 1 paper, etc.

Award received

【AY 2020 Geotechnology Research Encouragement Award 】

Tomohiro Toyoda: Development and verification of a soil-water coupled finite deformation analysis based on u-w-p formulation with fluid convective nonlinearity.
(https://doi.org/10.1016/j.sandf.2019.o3.008)

Editorial Afterword

Even while activities have been continuing in abnormal ways under the constraints of the Covid-19 pandemic, there were two very cheering pieces of news for the GEOASIA Research Society in this last year. The first was the distinction achieved by Tomohiro Toyoda (Nagoya University), a member of the Society and a GEOASIA Master, of a Geotechnology Research Encouragement Award. His paper dealt with an intensely difficult subject matter: the problem of how to perform a soil-water coupled deformation analysis based on a full formulation. In view of his success with this challenge, we can expect the GEOASIA software to see a still greater expansion in its scopes and applications. The second good news was the return of Professor Toshihiro Noda, the Society's current director, from his post at the Nagoya University Disaster Mitigation Research Center to an appointment of leadership in the Civil Engineering School within the university's Engineering Department. This development, too, I believe, will have an impact on the future growth of GEOASIA and our Society. Our strength has to come first from all of our members, however, and as always, we trust above everything in their support and goodwill.

A final word: The photograph of the President chosen to accompany his Message this time was not taken fifty years back, but we confess to thirteen years. But even at age 61, we feel he didn't look so very much different from now. (Toshihiro Takaine)