GEOASIA Bulletin No.16

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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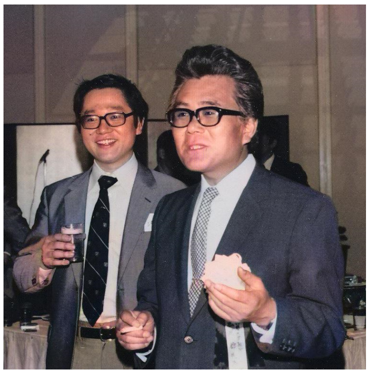
Message from the Society President



Just before I wrote this message, former prime minister Shinzo Abe was shot dead in a crude act of violence. A depressing blow to us all. In Japan we are becoming sadly accustomed to grim occurrences of this sort.

The appearance of Bulletin No. 16 gives a span of fifteen complete years to look back on, and the shock left behind by the former prime minister's terrible end leads me to think back over them. One thing that occurs to me is that in these 15 years of writing these Messages, I have never spoken yet of how much I owe to Professor Minoru Matsuo. He was another figure who departed from us too soon, before his time and still in the prime of his vigor.

When he died in 2015, Matsuo was 78. In July that year, a request came for me to write his obituary in Soils and Foundations, the journal of the Japanese Geotechnical Society. What I wrote there was accurate and as it was written only eight years ago it is still easy enough to find for anyone wishing to look it up. I hope some readers will. But it was limited to one page, and my deeper feelings had to be left out.

Matsuo had originally been preparing for a graduation thesis at Kyoto University under Professor Sakuro Murayama. But as circumstances turned out, he had to tie up his preparations hurriedly at the planning stage (under Professor Yoshimi Nagao) and then take a year off from university to go to the Himalayas with the Academic Alpine Club of Kyoto as leader of an AACK Bhutan Academic Exploration Expedition. When he returned from that time out to join Nagao Sensei's graduate school class, it happened to be just when I was moving up to graduate school after my fourth undergraduate year. And that chance brought us together. It would have been around 1970.

The Akaike Information Criterion (AIC) for the minimization of information loss was first unveiled at an international conference in 1973 as an extension of methods for the estimation of maximal likelihoods. But the first opportunity I had myself of hearing Hirotsugu Akaike in person lecturing on AIC was at Kyoto University in 1975. Assuming ten points of data in the coordinate space defined by axes x and y, if a ninth power equation is construed for this system it is possible to obtain a fit for all the data, but in reality, no one would ever do that. Normally, we make do with $y = a_0 + a_1 x$ or, at most, $y = a_0 + a_1 x + a_2 x^2$. The reason for stopping here is because of a minimization norm (the AIC) leading us to select the expression we estimate as most likely to match the principle of parsimony (or minimum required effort). Matsuo and I later made use of this new type of information quantity criterion to develop a model of effective stress distributions for the undrained shear strength of a clay soil, which we presented in 1977 at a conference in Tokyo of the International Society for Soil Mechanics and Geotechnical Engineering. But to be honest, neither of us would have said at the time that this research left a particularly deep impression on us. I also gave other presentations at that Tokyo ISSMGE conference, but I have long since forgotten what they were about.

What did have an eye-opening impact, however, was an encounter with the Rosenblueth Method (1975). Matsuo Sensei's specialty field, however you look at it, was the area of reliability in geotechnical design. Reliability design is not inherently a difficult subject to talk about, but the calculations for it are formidable. Essentially, if you take a probability variable X, reliability design can be thought of as a problem of finding probability distributions for Y in some relation Y = f(X). Generally, the mean values and dispersions for Y would need to be found from a Taylor series of mean values and dispersions of f(X) around mean X (the first order second moment method). But let us think, for example, of the case of a circular arc slip analysis ϕ u = 0 where X is the undrained shear strength of a clay soil and Y is a required safety factor. As is well known, the whole point of a circular slip analysis is to find the maximum slip surface arc radius compatible with a minimum of assured safety. In terms of plasticity theory, this is the equivalent of an upper limit problem: without this limit arc value for assured safety, a circular slip analysis cannot be mechanically sound. As for performing the calculation, after an arduous series of trial-and-error attempts, the analyst finally closes in onto one X = x value from which the safety factor requirement Y = y can be determined. But in this stage of the process, everything is indeterminate. There is no way of formalizing f(X) analytically in advance, or of finding first- and second-order derivatives that will lead to the solution. And for all the talk of "Monte Carlo simulations", there are plenty of circular slip analyses that do not lead to realizable outcomes. As an alternative to this hit and miss approach, the Rosenblueth Method replaces all of the probability distributions of serial probability variable X with just 2 points of scatter data and then conducts just two circular slip analyses on these to obtain the corresponding probability distributions for safety factor Y. For closer details, go to the references indicated below. By multiplying the data points for the probability distribution and so on, there are also further ways of enhancing the accuracy, but there is no need to go here into matters of that kind.

Up until that time, Professor Matsuo had always worn an embarrassed look when talking about the crudeness of these "reliability analyses" that seemed to lack (indeed, still do usually lack) any rational criterion of arc radius for the required minimum of safety. But from then on, it was a joy to see his years of accumulated frustration progressively brightening and turning sunny. I never ceased to be surprised by the quickness of his insights. But I also remember him as a dogged worker who tolerated no compromises where academic excellence was on the line and who cherished his life as a true scholar.

Let me end with some lighter memories overheard from other colleagues. When Professor Nakano was promoted to professor, he shocked everyone by coming out with the remark, "Asaoka Sensei has never touched real clay, you know." Another memory is of Professor Kodaka, now head of the Academic Support Center at Meijo University, being troubled while performing his water penetration tests in a sandy soil up to the point of soil failure in case the ordinary water he used from the mains supply would cause "air bubbles to pop up everywhere and create problems." Kodaka was serious and not a drinker, but Asaoka, the only person there who drank like a fish every evening, would say, "What's wrong with that? It is one way to turn water into beer." I remember Professor Noda, too, saying point blank at a department meeting – maybe around the time he was promoted to assistant professor – "From the time I was a student, I was always the one who made Professor Asaoka's exams, and then had to mark them as well." Well, what can I reply? Nothing. All of those stories were true. And they all also applied about as much to Matsuo as they did to Asaoka. Of course, Matsuo went on later to become President of the University, and there was no way they could have let Asaoka do that. But apart from that, in the rest of our doings and dealings with our students, we were pretty much alike. What memories. Those were the days.

Reference 1. Emilio Rosenblueth. “Point estimates for probability moments”. *Proc. Nat. Acad. Sci. U.S.A.* Vol. 72, No. 10, pp. 3812-3814, October 1975.

Reference 2. Akira Asaoka and Minoru Matsuo. “A simplified procedure for probability based ϕ u = 0 stability analysis”. *Soils and Foundations*. Vol. 23, No. 1, pp. 8-18, March 1983.

Akira Asaoka

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

Emeritus professor, Nagoya University

Research Results in 2021

(1) Simulation of the deformation and failure of an unsaturated slope in a rainfall modeling test

The soil-water-air coupled GEOASIA analysis was used to simulate the deformation and failure of an unsaturated slope in a rainfall modeling test. The test consisted in constructing an unsaturated slope of Kasumigaura sand (K sand) on a foundation of DL clay and then sprinkling it from above with water. Figure 1 shows results of pore water pressure distributions obtained in experiment and calculation for a rainfall intensity of 100mm/h. Comparing the two sets, it is clear that the rainwater infiltration beneath the surface of the slope is well reproduced in the analysis. Figure 2 shows the extent of the failure at the slip line for the same rainfall intensity. The analysis succeeds in representing the slip behavior along the whole of the slope from the toe progressing up to the shoulder. There is no room for detailed discussion here but in the soil element at the top toe of the slip surface, softening with plastic volume expansion above the critical state line q=Mp' results in major deformation. Figures 3 and 4 show the differences in slip failure behaviors, 3 (a) and (b), and distributions

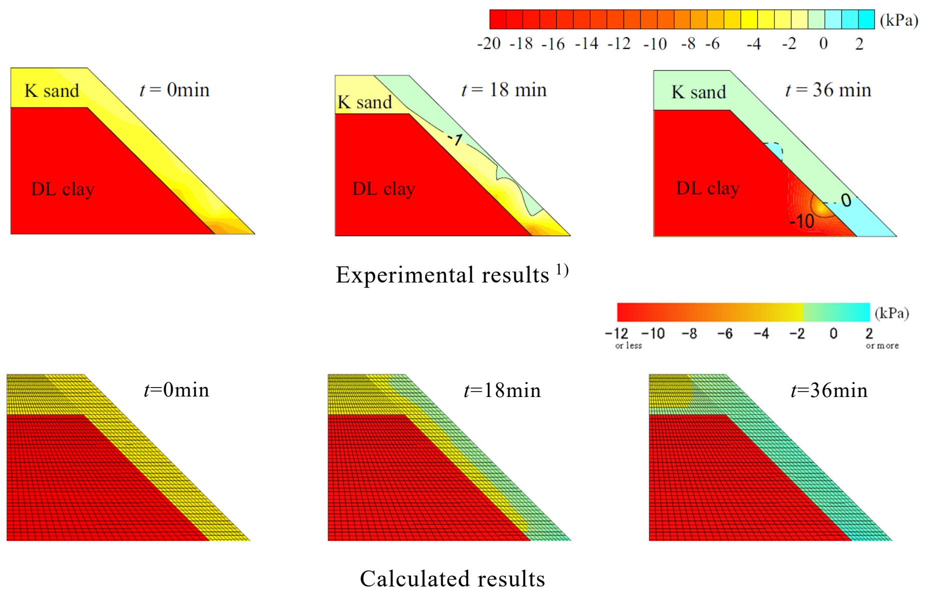


Fig. 1 Pore water pressure distributions for rainfall intensity 100mm/h

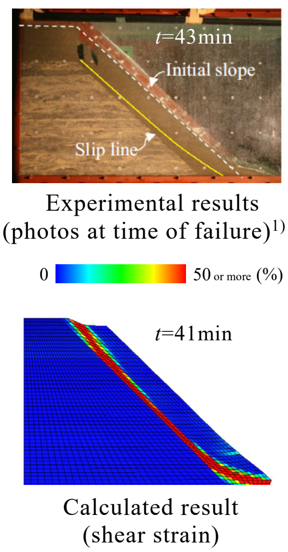
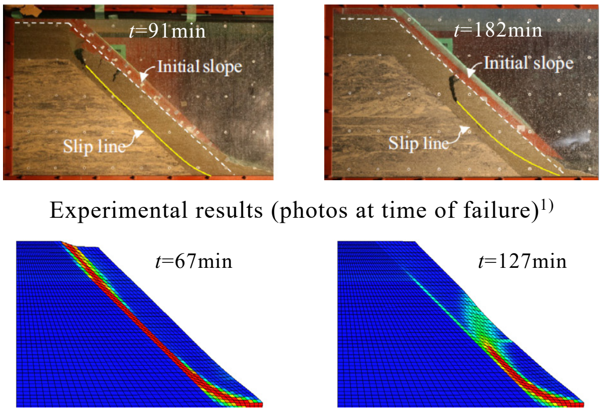


Fig. 2 State of slip failure for 100mm/h

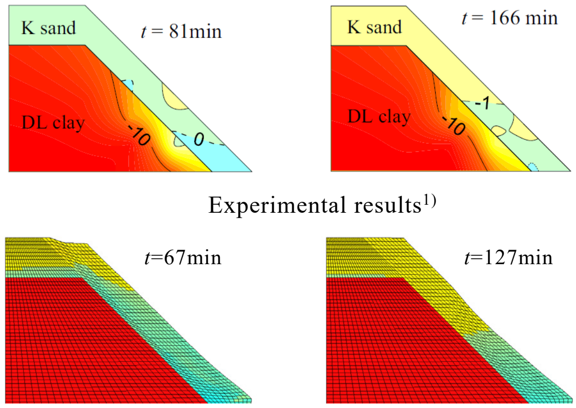


Experimental results (photos at time of failure)[1)]

Calculated result (shear strain)

(a) For 50mm/h (b) For 25mm/h

Fig. 3 Variation in slip failure behavior by rainfall intensity



Experimental results[1)]

Calculated results

(a) For 50mm/h (b) For 25mm/h

Fig. 4 Variation in pore water pressure distributions by rainfall intensity

of pore water pressure, 4 (a) and (b), for rainfall intensities of 50mm/h (a) and 25mm/h (b). The scale of the contour diagrams is the same as in Figures 1 and 2. A comparison of these less intense rainfall results with those for 100mm/h in Figures 1 and 2 shows that while the slip line reaches only as far as the middle of the slope for intensity 25mm/h, with an increase to 50mm/h it runs all the way to the top, and this is also well simulated in the calculated analysis. The reason for this behavior is that once the rainfall attains a certain intensity, the pore water pressure in the slope goes on rising until the slip line reaches the top.

1) Chueasamat, A. et al.: Experimental tests of slope failure due to rainfalls using 1g physical slope models, *Soils and Foundations*, 58(2), 290-305, 2018.

(2) Soil-water coupling 3-D finite deformation analysis of a large-scale test for a vacuum consolidation ground treatment

GEOASIA was used to obtain a 3-D analysis of a simulated large-scale test for a vacuum consolidation treatment[2)] designed to accelerate consolidation and control delayed settlement in a foundation on reclaimed ground filled with dredged sediment (see Figure 5). The simulation was found to give a good replication of actual test results. Figure 6 compares changes in the rates of settlement, and Figures 7 and 8 changes in the pore water pressure in drained and undrained parts of the foundation respectively, at various ground levels. The actual and calculated results match up well in all cases. Figure 9 visualizes how the site will appear after the negative pressure has extended at all levels along the whole length of a drain leading to the early stages of compression in the adjoining soil. To solve a consolidation problem of this kind in which non-consolidated sediment is represented as being subjected to great pressure, the analysis needs to offer four capabilities: ① an elastoplastic constitutive equation supplemented with a concept of super- and sub-loading surfaces to allow the representation of soil behaviors in colloidal states, i. e., with high pore ratios, or pore water pressures exceeding isostatic, prior to the start of consolidation, ② in addition to accurate measurement of settlement and compression over time, the provision of a soil-water coupled finite deformation analysis that can go on tracking the water step by step as calculations proceed, ③ the inclusion of a permeability model correlating with the compression state of the soil, and ④ the capability of including a vertical analysis plane in the model. All of these capabilities are assured in the GEOASIA analysis.

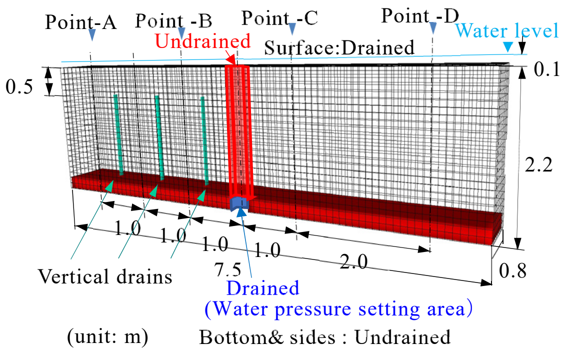


Fig. 5 Finite element mesh and boundaries

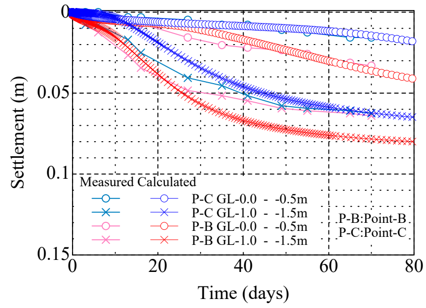


Fig. 6 Settlement by ground levels

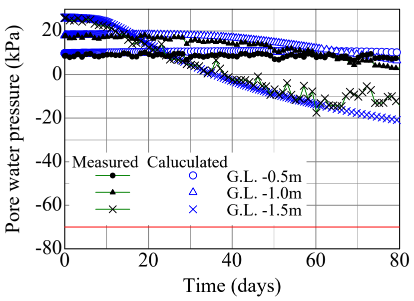


Fig. 7 Pore water pressure, without drains (Point C)

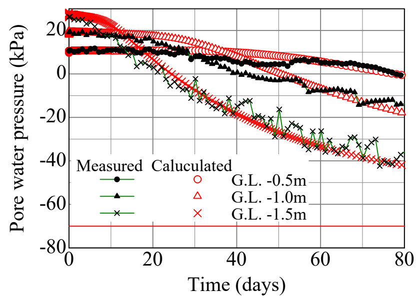
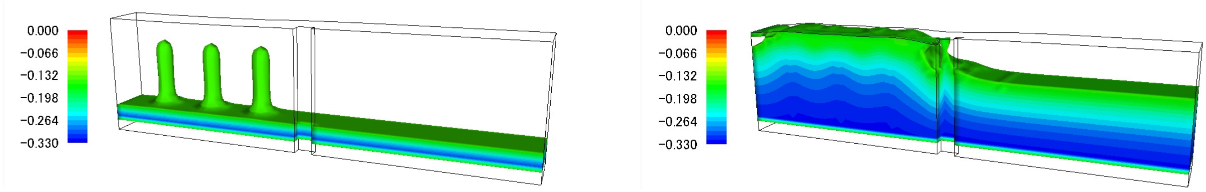


Fig. 8 Pore water pressure, with drains (Point B)



(a) After 7 days

(b) After 80 days

Fig. 9 Change in volume (Showing values of -0.15 and below)

(3) Reexamination of the earthquake resistance of an actually existing river levee, taking special note of the input frequency characteristics

In earthquake resistance inspections for river levees as currently practiced, a static mode of referencing is recommended, with too little attention paid to seismic frequency features and ongoing time effects. In the present research, therefore, a reinspection of earthquake resistance was undertaken for a levee on a soft soil foundation, taking particular note of input wave frequency patterns. Assuming a Nankai Trough earthquake and its expected impact on the river area concerned, the reference data used for the input tremor were, first, a short-period set issued by the Cabinet Office in 2011 (set A), second, a long-period set, also issued by the Cabinet Office, but in 2015 (set B), and, third, a hybrid set combining these two (set C). See Figure 10. For an A-type earth tremor in which the short-period component predominates, the bulk of the damage was found to be concentrated in the embankment and surface sand layer, whereas for a B-type tremor dominated by the long-period component, the more serious damage was to the clay layers deeper down. This difference in the locations of greater relative damage depends on the consonance or dissonance between the wave frequency periods and the eigenfrequencies of the component foundation layers. Clearly, in a C-type tremor of vast regional extension, the impact is equally destructive to both the sandy surface layers and the lower down clay ones, resulting in maximal damage to the whole levee structure at all levels. To be able to predict damage of this most severe kind, it is important not to lose sight of the possibility of earth tremor frequencies coinciding with natural frequency periods in the foundation layers. The lesson to be drawn from this is simple: Unless a variety of earth tremor scenarios is foreseen and provided for, there will always be a risk of underestimating the hazards.

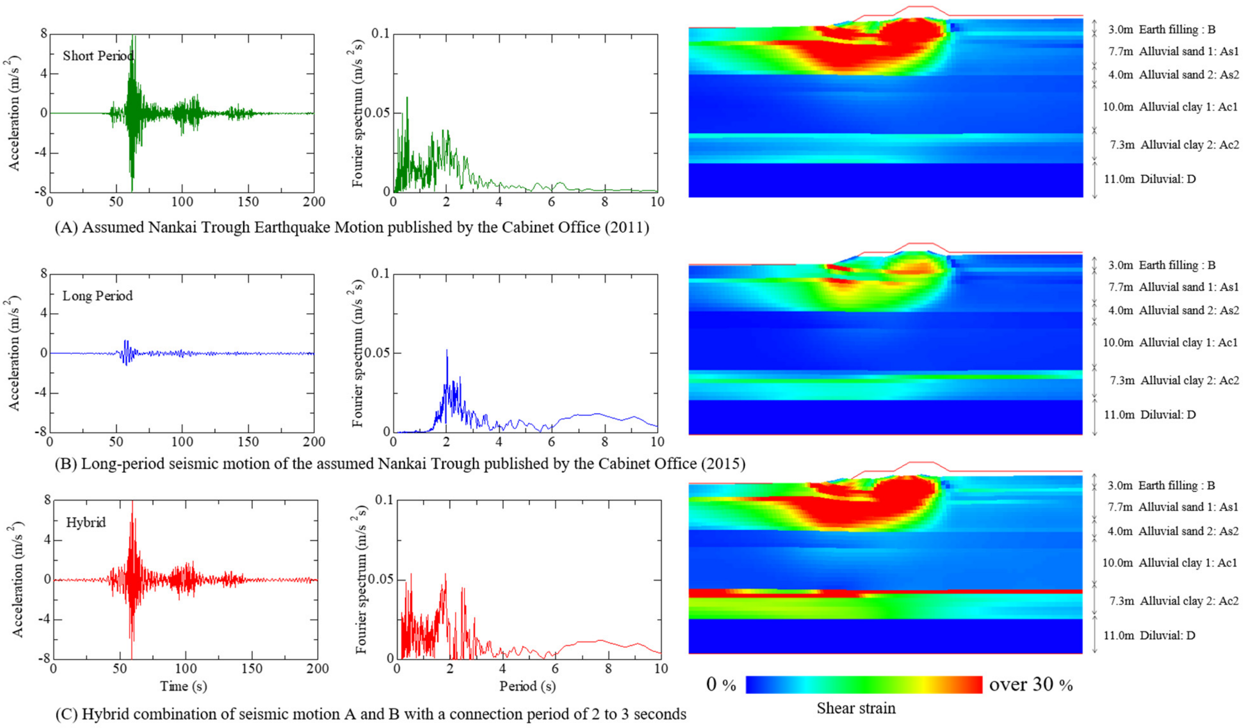
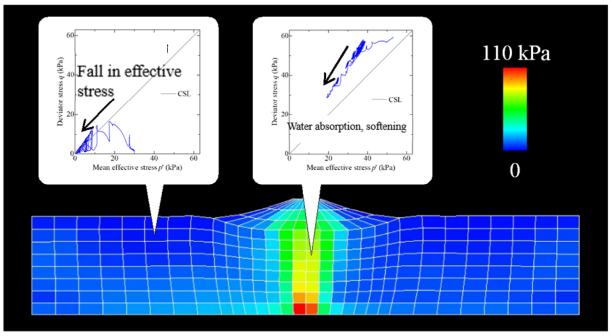


Fig. 10 Differences in input frequency characteristics and shear strain distributions immediately after earth tremor

(4) Application of a full formulation analysis to a condition of instability discovered in a foundation

In a soil-water coupling analysis based on a $\boldsymbol{u}$-p formulation that assumes a statically constant rise in the permeation rate of pore water through the soil skeleton, it is well-known in practice that divergences appear in the numerical results not only in cases of a high permeability coefficient k, but in any analysis where the time step interval Δt for the measurement rate is too small. In phenomena such as liquefaction or boiling, characterized by a lowering in effective stress and hence a progressive loss in ground rigidity, but also in instability problems such as slip failure or dynamic buckling, as there has to be a progressive rise in the displacement increment through the time series analysis to keep step with the ongoing stability loss, there will also be a corresponding ongoing need to reduce the time step interval in order to maintain the required degree of accuracy for the time differential Δt. This is what makes it cumulatively more difficult to continue with a calculation using the static $\boldsymbol{u}$-p formulation. To overcome this, if use is made of a full $\boldsymbol{u}$-$\boldsymbol{w}$-p formulation taking account of the relative acceleration in the pore water permeation rate, the above-described divergences in the numerical values can be eliminated, making it possible to keep continuous track of the deformation behavior resulting from the earlier stability loss. As examples, two $\boldsymbol{u}$-$\boldsymbol{w}$-p formulation analyses were performed to obtain the dynamic deformation responses, first, of a sand-clay foundation system destabilized through the liquefaction effect of an earthquake striking from outside (Figure 11) and, second, of a boiling phenomenon caused by a steep water flow gradient (Figure 12). For either of these sets of conditions, an analysis using a static $\boldsymbol{u}$-p formulation is found to lead into divergences, while a similar analysis using a $\boldsymbol{u}$-$\boldsymbol{w}$-p formulation permits the calculation to run through to the end. This points to the superiority of the $\boldsymbol{u}$-$\boldsymbol{w}$-p formulation for unstable state analyses of this kind.



At point of maximal acceleration, the curve for the fall in mean stress stabilizes allowing the calculation to continue

Fig. 11 Mean effective stress distribution obtained from liquefaction analysis (***u***-***w***-*p*)

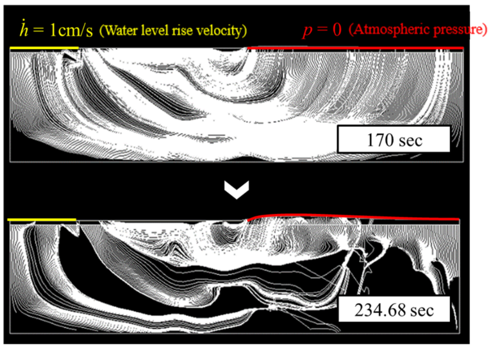


Fig. 12 Flow turbulence pattern obtained from boiling analysis（***u***-***w***-*p*）

(5) Use of the SYS Cam-clay model to replicate the shear behavior of sand reinforced with an admixture of PVA fibers

The aim of this research was to devise a method for the replicable manufacture of test specimens made of sand with an admixture of PVA fibers and to use these specimens for the performance of drained and undrained triaxial compression tests varying such factors as the PVA fiber dosage (dose of PVA fiber as a mass percentage of the sand in the dry state), initial relative density, and constraining pressure. Figure 13 shows results from a drained shear test series for a PVA fiber dose of 0.4%, three different grades of initial relative density, and a constraining pressure of 100kPa. While differences appear in the shear behaviors and dilatancy properties depending on initial relative density, the q, p' and v values all come to agree at the end of the shearing process, providing the constraining pressure does not change. As the same result reoccurs when the dose is reduced to 0.2%, this indicates that the end of shearing may be regarded as a limit state condition, allowing this behavior of the sand-PVA fiber mixture to be interpreted in terms of limit state soil mechanics. Building on this theoretical basis, an attempt was made to use the SYS Cam-clay model to replicate similar test series. The analysis results obtained can be seen in Figure 14.

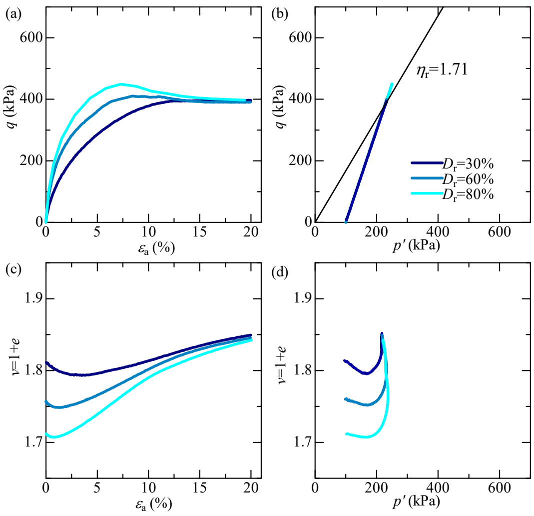


Fig. 13 Drained triaxial test results for different initial relative densities(PVA fiber dose 0.4%)

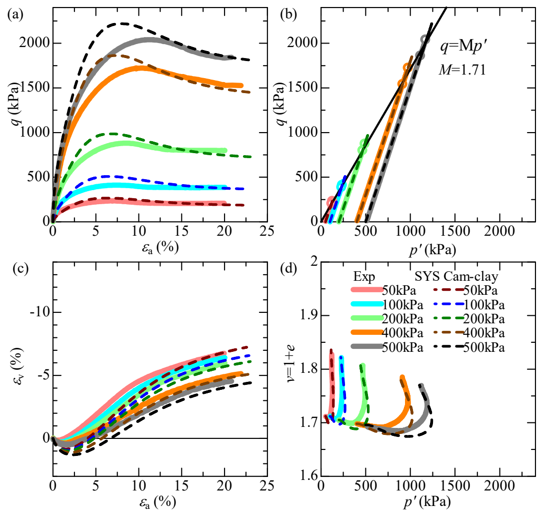


Fig. 14 Drained triaxial test and analysis results for different constraining pressures (PVA fiber dose 0.4%)

(6) Deformation restraining effect of a double steel sheet pile reinforcement method used to protect a river levee on a soft foundation of alternating sand and clay layers from damage in the event of an L2 earthquake

How to determine appropriate earthquake resistance assessment and protection measures for river levees is an urgent issue. In a study addressing this problem, GEOASIA was used to investigate the reinforcement effectiveness of a system of double steel sheet piles driven into the shoulders of a pair of river levees resting on foundations with alternating layers of thickly deposited soft clay (N value close to zero) and sand (see Figure 15). From the results, it was found that the use of steel sheet piles in the form of pipes greatly reduced the occurrence of soil slips within the clay layers as well as inhibiting stretching and settling behaviors in the levee slope. This effect continued beyond the duration of the earthquake, highlighting the constraining benefit that can be expected from a system of this sort as a precaution against large-scale deformations originating in soft clay layers. Figure 16 shows shear strain distributions 90 seconds after the start of the earthquake and at the time the tremor ends. Figure 17, for the left bank only, shows the amounts of settlement at the toe and shoulder of the levee embankment slope for the two cases 1, without, and 2, with this reinforcement measure, and Figure 18, also for the left bank only, shows the time paths of the horizontal displacement processes in each case, again at the toe and shoulder positions. Looking first at case 1 (no reinforcement), in addition to the liquefaction and ensuing settlement that occur in the sandy surface soil just after the earthquake, the disturbance in the very soft clay layer (N: almost zero) directly under the levee sets off diagonal slips, indeed slumps, in the foundation soil that not only cause further settlement in the levee but raise the bed of the river and reduce its flow volume. At the same time, under the added impulsion of the soil slips just below the levee structure, the levee itself undergoes stretching to an additional length of around 3.5m. It used to be generally thought that risks of earthquake damage were minimal with soft and well-structured clay soil layers, but results like these suggest that especially in a setting like this where the foundation below a levee is subjected to uneven loads, settlement and slip hazards exist when an earthquake strikes and the ground damage that they lead to may be severe.

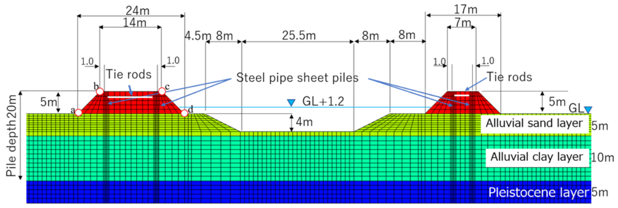
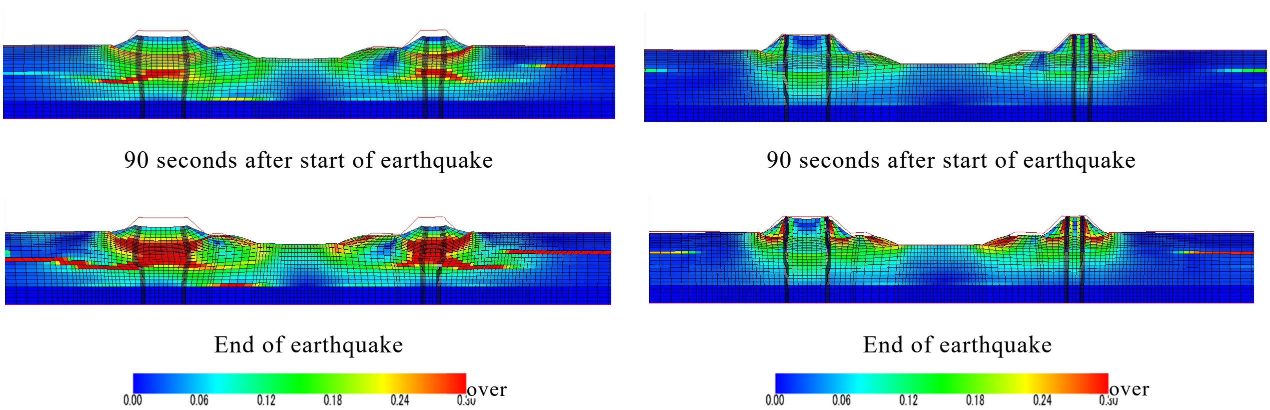


Fig. 15 Analysis conditions (showing levee and embankment section, width of analysis area 1000m)

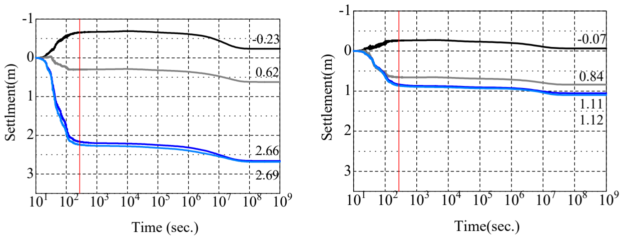


90 seconds after start of earthquake | 90 seconds after start of earthquake

End of earthquake | End of earthquake

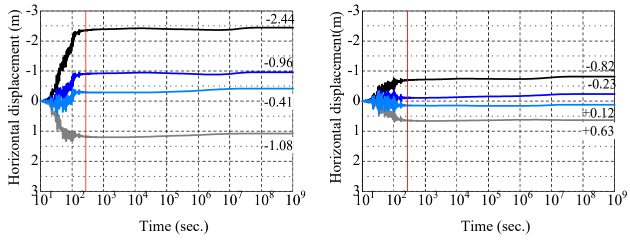
(a) Case 1 (no reinforcement) | (b) Case 2 (reinforcement)

Fig. 16 Shear strain distributions



(a) Case1 (b) Case2

Fig. 17 Left bank levee embankment, settlement at toe and shoulder



(a) Case1 (b) Case2

Point a, Point b, Point c, Point d

Fig. 18 Left bank levee embankment, horizontal displacement at toe and shoulder

In case 2 (reinforcement through steel pipe sheet piles driven through the levee shoulders to a depth of 20m), these settlement and lateral displacement risks due to liquefaction in the sand layer and soil slips in the clay are seen to be held in check.

Principal publications etc. in Academic Year 2021 (April 2021 – March 2022)

Academic papers:

【Soils and Foundations】

1) Attempt to reproduce the mechanical behavior of cement-treated soil using elasto-plastic model considering soil skeleton structure, Soils and Foundations Vol.61, Issue 5, pp. 1464-1474, 2021.

2) Importance of considering unsaturated triaxial tests including ceramic disk as initial and boundary value problems, Soils and Foundations, Vol. 61, Issue 3, pp. 901-913, 2021.

3) Numerical simulation based heuristic investigation of inertia-induced phenomena and theoretical solution based verification by the damped wave equation for the dynamic deformation of saturated soil based on the u–w–p governing equation, Soils and Foundations, Vol.61, Issue 2, pp. 352-370, 2021.

【Journal of Geotechnical and Geoenvironmental Engineering】

1) Method to Introduce the Cementation Effect into Existing Elastoplastic Constitutive Models for Soils, Journal of Geotechnical and Geoenvironmental Engineering, Vol.148, Issue 5, 2022.

2) Verification of a macro-element method with water absorption and discharge functions in quasi-static problems, Journal of Geotechnical and Geoenvironmental Engineering, Vol.148, Issue 7, 2022.

【Journal of Applied Science】

1) Effects of strong ground motion with identical response spectra and different duration on pile support mechanism and seismic resistance of spherical gas holders on soft ground, Journal of Applied Science, Vol. 11, No. 23, pp. 11152, 2021.

【Journal of Rock Mechanics and Geotechnical Engineering】

1) Effect of fiber-reinforcement on the mechanical behavior of sand approaching the critical state, Journal of Rock Mechanics and Geotechnical Engineering, Vol. 14, Issue 4, 2021.

【Computers and Geotechnics】

1) Combined-loading elastoplastic constitutive model for a unified description of the mechanical behavior of the soil skeleton, Computers and Geotechnics, Vol.141, 2022.

2) Numerical analysis of drained compression behavior of fiber-reinforced sand based on a soil skeleton structure concept, Computers and Geotechnics, Vol.148, 2022.

【Journal of JGS】

1) Evaluation of mechanical behavior of river levee under combined external force of earthquake and water level by a soil-water-air coupled finite deformation analysis, Journal of JGS, Vol. 70, No. 3, pp. 10-13, 2022(in Japanese).

【ISSMGE International Journal of Geoengineering Case Histories】

1) Ex-post evaluation of countermeasures against residual settlement of an ultra-soft peaty ground due to test embankment loading: A Case study in Maizuru-Wakasa Expressway in Japan, ISSMGE International Journal of Geoengineering Case Histories, Vol. 7, Issue 1, pp.59-75, 2021.

【The Foundation Engineering and Equipment Monthly】

1) Draining of electric utility poles as a measure against liquefaction: Use of a centrifuge model test and numerical analysis to verify the deformation control effect in the event of an earthquake, The Foundation Engineering and Equipment Monthly, Vol. 49, No. 5, pp.81-84, 2021(in Japanese).

International conferences:

【IX International Conference on Coupled Problems in Science and Engineering (COUPLED 2021)】

1) Clarification of water absorption failure mechanisms of unsaturated silt triaxial specimen through three-phase elastoplastic finite deformation analysis considering inertia force, IX International Conference on Coupled Problems in Science and Engineering (COUPLED 2021), 2021.2.

2) Evaluation of the performance of u-p formulation-based analysis by the ***u-w***-p formulation-based analysis in oscillation problem, IX International Conference on Coupled Problems in Science and Engineering (COUPLED 2021), 2021.

【11th International Conference on Geotechnique, Construction, Materials and Environment】

1) Seismic performance evaluation of PFS method by soil-water coupled finite deformation analysis, 11th International Conference on Geotechnique, Construction, Materials and Environment, gxi 381, 2021.

Domestic conferences:

【2021 Japan Geoscience Union Meeting (May, 2021)】 3 papers.

【26th Conference of the Japan Society for Computational Engineering and Science (June, 2021)】 2 papers.

【56th Japan National Conference on Geotechnical Engineering (July, 2021)】 9 papers.

【33rd Chubu Geotechnical Symposium（August, 2021）】 3 papers.

【76th Japan Society of Civil Engineers Annual Meeting（September, 2021）】 5 papers.

【9th JSCE River Embankment Engineering Symposium（December, 2021）】 1 paper.

【AY 2021 JSCE Chubu Chapter Research Reports (March, 2022)】 3 papers, etc.

Editorial Afterword

The photograph accompanying the president's Message in this issue was a shot taken at the celebration party for Minoru Matsuo's promotion to the rank of professor 44 years ago in 1978. The cigarette never far from his right hand was a signature feature and is a fond memory for some of the older among us. Asaoka Sensei began his teaching appointment at Nagoya University the following year. The picture was originally black and white, as shown on the right, but nowadays it is perfectly easy to have a photo colorized making use of AI techniques. How soon will it be before all the articles in this Bulletin can be composed this way? Only the Message from the President belongs in a realm of its own and defies AI, I would think. (Toshihiro Takaine, now based in Nara).