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APPLIED MECHANICS AGAINST THE ARTS OF GEOTECHNICAL AND COASTAL ENGINEERING

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This essay deals with interactions between applied mechanics and geotechnical and coastal engineering. Its aim is to answer some basic questions concerning the influence of applied mechanics on the above specializations and vice versa, as well as to identify practical problems which could be inspiring for applied mechanics. The above problems are discussed within the framework of soils' plasticity and mechanics of mixtures.

1. INTRODUCTION

Mechanics is the branch of physics that deals with the motion of bodies and the action of forces on bodies. *Applied* means *used in actual practice or to work out practical problems* (see *Collins Pocket Dictionary*). The role of applied mechanics in the development of our civilisation cannot be overestimated, since this subject has strongly influenced our every-day life. We have been using the methods of applied mechanics for rational designing of a variety of useful things which afford us safety and comfort. On the other hand, the methods of applied mechanics have been used to investigate various processes appearing in the natural world, in order to protect ourselves from natural disasters or to make the most of natural resources.

Applied mechanics is deeply rooted in practical sciences including civil engineering, as we learn from history, see TIMOSHENKO [44]. It was developed in the past harmoniously with technological advancements, and the most important theoretical achievements were strictly connected with the real problems. On the other hand, the methods of applied mechanics have essentially influenced civil engineering by providing powerful tools, enabling more and more rational designing of various materials and structures. It seems that such almost ideal cohabitation had existed up to the middle of the past century. Since then, the gap between civil engineering practice and theoretical achievements of applied mechanics has been expanding to the point where both specializations exist almost independently. Because of such a situation, it is necessary to review the goals which should be achieved in recent times by both the applied mechanics and civil engineering sciences. In particular, it would be interesting to identify problems of considerable importance, of sound meaning and which would also be of major concern to applied mathematicians as a source of fruitful theoretical investigations. In the present paper, only a part of this problem will be discussed, namely that connected with geotechnical and coastal engineering.

It appears that the past practical philosophy has been forgotten at present, and therefore, we should submit the important question as to the interactions between contemporary applied mechanics and the above-mentioned specializations. More specific questions deal with such problems as: How has the mechanics of solids influenced the progress in civil and environmental engineering ? Which practical problems could be inspiring for mechanics of solids, etc. ? It is impossible to answer these questions comprehensively, but an attempt will be made to obtain at least some partial answers and provide a general framework for future discussions on the problems. Such a discussion is greatly needed in these difficult times, particularly in Poland, where scientific investigations have been extremely underestimated by politicians and probably by the vast majority of our society.

In this paper, some problems related to the applied mechanics theories of plasticity and mixtures will be discussed in the context of real problems of practical importance. The examples chosen arise from a variety of research tasks investigated in the Institute of Hydro-Engineering. The Institute's research and development activities cover the basic and applied problems related to inland and maritime hydro-engineering, geotechnics and geomechanics, as well as other disciplines connected with civil and environmental engineering. These activities are based on, amongst other things, the methods of applied mechanics, including hydrodynamics, elasticity, plasticity, rheology, etc. Application of these methods to the analysis of actual problems reveals both their positive and negative features, and therefore enables identification of the desired research directions.

2. DOES ENGINEERING NEED ADVANCED APPLIED MECHANICS ?

The methods of applied mechanics have been succesfully adopted in civil engineering for decades, and it is difficult to imagine the practical developments around us without these methods. There are three main theoretical supports of civil engineering, namely: structural mechanics and strength of materials, mechanics of fluids and hydraulics, and soil mechanics; each of them being a separate specialization of applied mechanics. Students had been taught these as standard subjects, and then applied them in their engineering work. These methods have been proven as very efficient tools, as we already can construct very tall buildings, sophisticated bridges, deep tunnels, artificial islands, drilling platforms, motorways, etc. Do we really need more advanced theoretical methods for designing these objects, or is the classical knowledge sufficient ?

This is a very difficult question, as is connected with many other factors such as, for example, economy, general education or needs of a narrow group of research workers. An interesting discussion of these problems is presented by KOLYMBAS [20]. According to his opinion, the contractors are not interested in more economical design, as they are paid according to the amounts of concrete and steel consumed. He does not think that research is an economic need but considers rather a human necessity, such as music and fine arts. More general discussion of these problems is presented by VIGGIANI [45], who has noticed a deterioration of civil engineering practice in the last decades, due to misuse of numerical methods, abuse of soil improvement techniques, etc. But Viggiani believes that mankind needs science, and that the use of science in engineering is possible only in the framework of a widespread scientific culture. It is interesting to note that the above opinions are very different from justifications of many research projects, financed by the Polish State Committee for Scientific Research (KBN), where the arguments on "significant practical implications" of the proposed programmes are frequently used. The above opinions are probably rather extreme, since Poland has not yet become a technological paradise and, on the other hand, there continue to be practical problems which require intensive research. Moreover, the arguments concerning 'scientific culture' or 'human necessity' may sound absurd in Poland, where scientific investigations have been systematically eliminated in recent years.

A great disadvantage for research workers in Poland is that a large number of modern technologies have been imported from more developed countries, hence the practical stimuli of practically oriented research have weakened significantly. Polish industry is deteriorating and foreign investors are not really interested in advancements in Polish science. Such a situation differs greatly from that existing in Poland after World War 2, when our country badly needed the reconstruction of the civil engineering infrastructure. There existed very real needs which had strongly inspired research in applied mechanics, as we can learn from the memoirs of Professor W. NOWACKI [24], one of the famous founders of the Polish school of applied mechanics (see also PRZYBYŁOWSKA [26]). Also interesting conclusions can be drawn from the biography of Professor ST. HUECKEL [15]. In those times, civil engineering really needed applied mechanics.

Recent times are obviously different, but there are still unsolved problems, and some of them can also be inspiring for purely theoretical investigations. The author believes that civil and environmental engineering still need advanced applied mechanics, and this conviction will be supported by some chosen practical problems.

3. PLASTICITY IN GEOTECHNICAL PROBLEMS

The theory of plasticity is the 'heart' of contemporary soil mechanics if measured by the number of various constitutive models, respective journals, publications or conferences. Modern plasticity was pioneered by Coulomb in the 18th century, after having worked on some fundamental soil mechanics problems. His concepts still form the basis of contemporary practical soil mechanics and geotechnical engineering, as follows from examination of current textbooks and analysis of the methods used by geotechnical engineers. According to SIMPSON [40], there are two fundamental engineering needs regarding the design and construction of various objects, namely reliable predictions of damage and displacements. Therefore, the role of soil plasticity is of basic importance in geotechnical engineering as it provides rational tools enabling the estimation of both the bearing capacity and deformations of earth structures. However, the very important question of quality of these rational tools, as well as their usefulness in practical applications is still open.

The opinions regarding quality and usefulness of soil plasticity differ greatly. ZIENKIEWICZ *et al.* [48] reckon that the great variety of existing soil models are able to deal with most of the observed features of the mechanical behaviour of these materials. More critical opinions regarding the constitutive relations, which are the central point of theoretical soil mechanics, have been formulated by BOLTON [5, 6] and KOLYMBAS [20]. For example: "Constitutive relations is a phrase which commands respect in the Universities and revulsion in practice. It lies at the heart of the gulf which has arisen between research and practice, and which damages both", BOLTON [6]. Or: "The main shortcoming in the field of constitutive modelling is that each researcher (or group of researchers) is developing his own constitutive model. This model is in most cases very intricate and, thus, non-relocative, i.e. no other researcher is able to work with it. I can report from my own experience that it took me several months of hard work until I realized that I was unable to obtain anything with a constitutive model proposed by a colleague", KOLYMBAS [20]. It is very good that such an open discussion on the quality and usefulness of soil plasticity has been initiated as the current state of this subject is truly controversial, see also SAWICKI [32, 33]. It is impossible, in this short paper, to present a comprehensive analysis of the current state of soil plasticity, but some important observations can be summarized as follows:

a. There exists a large gap between theoretical and practical soil mechanics which has been developed almost independently. A large number of constitutive models of soils have already been proposed, but none of them has positively passed the basic experimental tests dealing with the stress-strain response, cf. SAADA and BIANCHINI [28]. Note that these are experiments which ultimately decide as to the value of a particular theory.

b. The only reliable theory, which constitutes the backbone of soil mechanics, is the theory of limit states, particularly the part connected with the lower-bound estimates of bearing capacity of earth structures. This theory enables reliable prediction of limit loads, sufficient for practical reasons. The most popular and efficient geotechnical methods, e. g. those of Bishop, Fellenius or Nonveiler, belong to this group. The theory of limit states is very well elaborated in geotechnical literature and has already become a kind of standard, see DEMBICKI [8], IZBICKI and MRÓZ [17], SZCZEPIŃSKI [42].

c. Mathematical structure of the classical theory of limit states is fairly simple and convincing from the physical point of view. It contains only two material parameters, namely the angle of internal friction and cohesion, which have clear physical meaning and are easy to determine in a standard geotechnical laboratory. This is very important for practical reasons. In geotechnical literature, one can often find critical discussions about these parameters, but it seems that we cannot expect a better alternative.

d. A great practical problem is determination of the strength parameters of soils in field conditions, as well as determination of geological structure of natural soils. In geotechnical engineering, there is a great deal of uncertainty and non-homogeneity. In practice, it is only possible to estimate the strength and other parameters of soils in chosen points of natural deposits. A common method of dealing with such problems is to perform thousands of calculations, obviously using a computer and the most simple methods of analysis as, for example, those of Bishop or Fellenius, assuming also some statistical distributions of strength parameters. Such calculations provide a general picture of soil stability and enable identification of most probable mechanisms of failure. The technique described is quite efficient. For example, TEJCHMAN *et al.* [43] applied the above method to study the stability of some Polish cliffs, and they were able to predict a spectacular failure of the Jastrzębia Góra Cliff and the associated damage of a historical building, cf. SAWICKI *et al.* [38]. The predicted failure surface, corresponding to the above mentioned event, is shown in Fig. 1

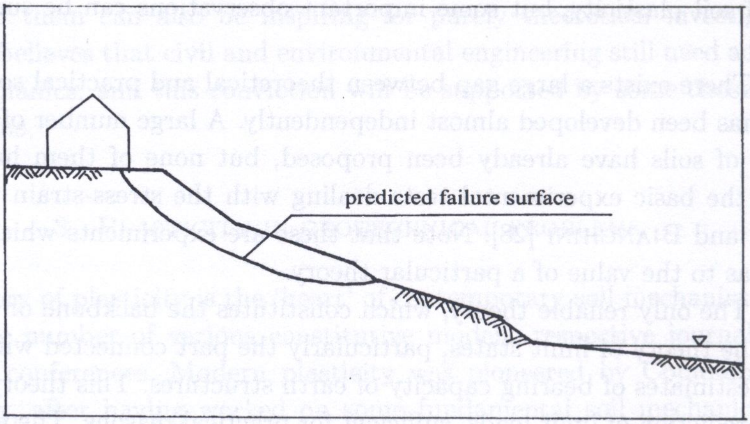

FIG. 1. Predicted failure of the cliff in Jastrzębia Góra. Prediction: 1995; Failure: 2002. The most simple methods are often very efficient.

e. Geotechnical engineers do not have efficient tools enabling reliable prediction of soils deformations before and after failure. In geotechnical literature, the methods of linear elasticity are customarily recommended, which is obviously wrong. Consequently, strange values of elastic soil moduli are reported, even without providing rational experimental methods of their determination. Extensive discussion of this problem is presented in SAWICKI and ŚWIDZIŃSKI [36]). Elastic moduli reported in the majority of geotechnical textbooks enlarge the existing chaos and are useless for practical applications.

f. An exceptionally large number of advanced elasto-plastic models of soils, and many others, display rather the poor situation of the current state of soil mechanics than its maturity. These models rarely give predictions which are conformable with experimental data, as demonstrated at several workshops, e.g. SAADA and BIANCHINI [28]. BOLTON [6] suggests that "Academics need to focus more on decision-making in design and construction, more on developing new technology, and less on mathematics which produces virtual predictions in a computer game environment". It should be added that advanced models of soils are characterized by a large number of material parameters, difficult to determine even in laboratory conditions, which makes them useless from the practical point of view.

g. Contemporary soil mechanics is based on the concepts of Coulomb and Terzaghi, and it seems that no original and effective ideas have emerged since those times. Major contemporary ideas have been copied from other subjects as, for example, metal plasticity. There is nothing wrong with adapting interesting solutions from other disciplines, provided it is really effective. Probably the only modern and original idea was proposed in Cambridge under the designation of 'critical state theory', see SCHOFIELD and WROTH [39], WOOD [46], ATKINSON [2], ATKINSON and BRANSBY [3]. However, this theory still needs further investigations, and mainly experimental verification. It is still treated as a 'student's model'. Progress in soil mechanics is measured rather by modern tools, such as computers and numerical methods or experimental devices such as geotechnical centrifuge etc., provided however by other disciplines. This richness of modern technological devices should supplement basic investigations in soil mechanics, but first new ideas should be proposed. BOLTON [5] thinks that the role of micro-mechanics will lead in the future geomechanical investigations.

h. It is impossible to grasp all the past and contemporary attainments of soil mechanics, as thousands of various contributions have already been published in numerous journals, conference proceedings, monographs and textbooks. Some narrow specializations are analyzed in state-of-the-art articles, which are valuable sources of information, although restricted to the authors' interests and knowledge. For example, in the Polish literature one can find such publications dealing with elasto-plastic models of soils, cf. GRYCZMAŃSKI [14] or JARZĘBOWSKI [18]. However, one can hardly find publications in which critical analyses of existing models of soils are presented. Almost unique are such publications as that of RIVLIN [27] who deeply analysed the endochronic theory of Valanis. It seems that the main problem is a lack of empirical validations of theoretical models of soils, which is a method enabling effective elimination of vague theories. The other problem is that most existing models are strangely formulated, as KOLYMBAS [20] has noticed, and therefore other researchers do not want to waste their time learning about such poor intellectual achievements. Consequently, the number of useless models is growing and soil mechanics is becoming probably the biggest dust-heap in technological sciences. There is an urgent need to improve the situation, and a national research programme is necessary, as I already suggested, SAWICKI [32].

4. LESSONS LEARNED FROM A SINGLE CASE STUDY

It is impossible in this short paper to either propose a universal medicine for the problems harassing contemporary soil mechanics, or to present statistical analyses of various practical problems and their connections with applied mechanics. It would be better to describe a particular case study, illustrating the contemporary state of practical soil mechanics, and also showing problems which need further investigations. An interesting case of geotechnical problems in the Dychów water power plant has been chosen for these purposes.

The plant was built nearly 70 years ago in the Bóbr river valley. From the very beginning, engineers were faced with several problems connected with local failures of slopes, caused mainly by difficult hydro-geological conditions on the site. Figure 2 shows a simplified cross-section of the slope, which is built of sands resting on an inclined firm stratum formed by natural cohesive soils. Obviously, each cross-section of the slope differs from others because of the complex geological structure of the site and it is therefore an averaged picture of the slope structure, drawn quite subjectively from available geological measurements. Geotechnical engineers often face problems with determination of geological structure of natural soil deposits and therefore subjective judgement plays an important role. They usually have some basic information from just a few boreholes and must deduce geological structure from these uncertain data. In the case of such engineered earth structures as, for example, artificial slopes or dams, the geometry of such objects is obviously known. In Dychów, altogether nearly 200 boreholes were made, which is a really impressive number, but despite that, there were long discussions regarding the geological structure of the site.

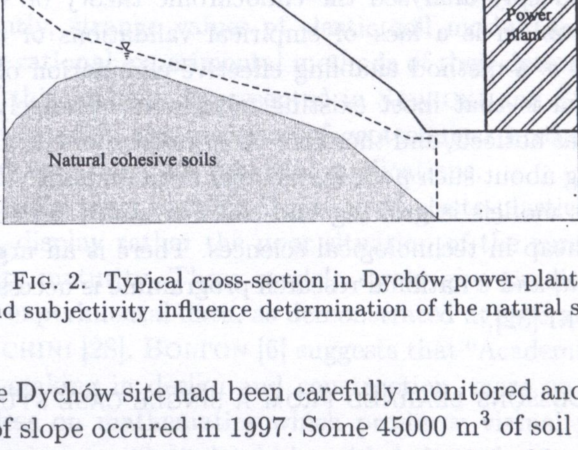

FIG. 2. Typical cross-section in Dychów power plant.
Uncertainty and subjectivity influence determination of the natural structure of soils.

Although the Dychów site had been carefully monitored and controlled, a significant failure of slope occured in 1997. Some 45000 m^3 of soil moved downslope causing considerable damage to the power plant, which had been out of order for 9 months. Rebuilding of the plant have cost an additional 15 million dollars. A hasty renovation of the Dychów site has created additional problems, connected mainly with the dynamics of the system: power plant-pipelines-surrounding soils. Significant vibrations of the slope were discovered, and the field measurements revealed that in some places, the ground accelerations exceeded even 0.1g. It is very probable that similar vibrations had been occurring before failure.

The causes of the catastrophic failure of the Dychów slope are still unclear. There are few realistic hypotheses regarding a possible mechanism of failure, but none of them has been proved convincingly. The first hypothesis assumes that the soil strength parameters have been degraded due to filtration processes. According to the other hypothesis, the static liquefaction of loose, water-saturated sands, triggered by dynamic impulse, had initiated the slope's failure. Another hypothesis suggests that liquefaction of sand at the contact surface with the stratum of cohesive soils, caused by vibrations, was a possible reason for initiation of failure. Extensive discussion of the above problems is presented elsewhere, see DŁUŻEWSKI and HRABOWSKI [9], DŁUŻEWSKI *et al.* [10], SAWICKI and ŚWIDZIŃSKI [36], WOLSKI *et al.* [47].

In most cases, stability analyses were carried out using the most simple methods such as those of Bishop and Nonveiler. Only in one case, was a more advanced method, based on the elasto-plastic model of soil and the finite element code, applied. However, due to lack of data concerning model's parameters, their values were assumed arbitrarily from different sources, even from an old textbook, written in times when the advanced model did not exist. It is obvious that arbitrary choice of material parameters enables the modelling of things which we wish to happen.

The parameters characterizing soils' properties can be determined either in the laboratory, from the behaviour of samples taken from boreholes, or estimated *in situ*. In Dychów, only some estimated values of the basic strength parameters were determined. It is hard to imagine how it would be possible to determine, say, 15 material constants or functions for each soil. The cost of determination of such parameters strongly influences practical usefulness of theoretical models. On the other hand, the final user of the theoretical model should have the possibility of guiding the parameters, therefore they should have some physical significance. For example, the angle of internal friction, hence the strength of granular soil, increases during compaction. A large number of physically insignificant parameters do not provide such a possibility.

The other important problem is determination of loads, both static and dynamic, including the influence of self-weight of soils. For example, a typical procedure is to assume geostatic stresses caused by self-weight, which is a rough approximation when compared with the real stress state in soil deposits. All these uncertainties, connected with determination of geological structure of natural soils, mechanical characteristics and loads, make the position of the geotechnical engineer uncomfortable as compared with the nice, clear situation in classical structural mechanics, where static schemes are usually much more precise. Moreover, some phenomena which appear in soils are still not clearly understood, or described, as static liquefaction, dynamic interaction between structures and surrounding soils, dynamic stability and vibrations of slopes, pore pressure generation and liquefaction in saturated soils due to cyclic loads, etc. There do not exist efficient engineering tools which would enable rational analysis of the above problems and it is a potential area for applied mechanics investigations. Geotechnical engineers deal with such problems using empirical methods or applying simple mechanical models which, however, are very distant from reality, cf. DAS [7], ISHIHARA [16]. Some attempts at elaborating consistent engineering theories have not gone far beyond academic discussions, see SAWICKI [29].

The Dychów case study illustrates most of the problems harassing contemporary soil mechanics and geotechnical engineering. Similar conclusions can be drawn from extensive and long-lasting investigations of geotechnical problems appearing during construction of the tailing dam "Żelazny Most" in the Lubin Copper Basin. Tailing dams are built of post-flotation deposits and support more than 300 million m^3 of waste material. It is the biggest reservoir of waste materials in Europe, the height of which is continuously increasing some 1.3 m per year. The Copper Mine wants the dam to be as high as possible, for obvious economic reasons, but local administration is afraid of eventual global failure of dams which would be extremely dangerous for the local population and infrastructure. Because of this conflict, different interdisciplinary teams of experts have been appointed, and have been analysing various aspects of reservoir's safety. Due to the construction technology, the soils building the dam are not well compacted, and therefore they can be susceptible to the danger of static liquefaction, particularly as the "Żelazny Most" site is located in a para-seismic region. It can be seen again that geotechnical engineers do not have rational tools which would enable rational analyses of such important problems. They believe in simple tools and empirical experience, which displays total failure of contemporary theoretical soil mechanics.

Some time ago, when I was young, I asked a prominent member of the Polish Academy of Sciences, who had propagated non linear, tensorial constitutive equations for anisotropic soils, how to determine all these material parameters. He burst out laughing and told me that this was none of the applied mechanics business. It was difficult to agree with such an opinion because the role of applied sciences must be practical from definition.

A fundamental challenge to research workers is to elaborate methods of determination of mechanical properties of geomaterials *in situ*. These basic mechanical properties deal with elasticity, plasticity, viscosity and strength, according to academic classifications. 'Determination of mechanical properties' usually means determination of parameters appearing in a particular model. For example, the angle of internal friction and cohesion are related to the Coulomb–Mohr yield condition. Respective values of these parameters provide important information about material properties because we have become familiar with respective models, and are able to relate the numbers to the quantitative response of this material. From the practical point of view, it would be very useful if such parameters could be determined from the measurements in field conditions. Such technologies have already been developed by geotechnical engineers, but there is still a lot to be done.

5. MECHANICS OF MIXTURES AND PROGRESS IN CIVIL ENGINEERING

Mechanics of mixtures is the other important specialization of applied mechanics which plays an important role in geotechnical and coastal engineering, as actual soils are mostly water saturated, and coastal sediments constitute two- or three-phase mixtures. The classical Terzaghi concept of effective stresses and Darcy's law of filtration are the basic theoretical principles in contemporary geotechnical engineering. On the basis of these principles, Terzaghi formulated his famous consolidation theory, which constituted a foundation for intensive investigations in continuum mechanics, starting from the Biot theory, through various mixture theories, up to contemporary mechanics of porous media which has attracted the attention of many research workers, see EHLERS [12], KUBIK *et al.* [21] and hundreds of various contributions dispersed in numerous journals and conference proceedings.

An interesting question is whether, and eventually how, the mechanics of mixtures has influenced progress in geotechnical and coastal engineering? Everybody feels that progress means positive changes or improvements as compared with a situation from the past. In civil engineering, we cannot expect such progress as is noted in telecommunications, computer sciences or medicine, which have substantially changed our every-day life. These achievements have been triggered by outstanding discoveries in physics. Thus, what is progress like in civil engineering? It may be associated with modern and economic technological solutions, new materials, smart structures (ANSARI, MAJI and LEUNG, [1]; SRINIVASAN and MCFARLAND, [41]), friendly infrastructure etc. According to BOLTON [5]: "... the industry is rapidly developing new technologies which must be optimised without the benefit of prior experience, and which may need to be tailored to the ground conditions. And notwithstanding the newness of the technology used in construction, there is no possibility of making a few prototype structures prior to the production run; Civil Engineering has generally got to work first time." The role of applied mechanics is therefore supportive and, as already mentioned, its main task is to provide engineering with efficient tools which would enable rational analyses of practical problems, as well as clever designing.

Classical structural mechanics and strength of materials are the best examples of such tools. A good engineer understands and "feels" these tools and is able to apply them with ease in practice, which may lead even to surprising and outstanding results, as in the case of many bridges or other structures. This is outstanding results, as in the case of many bridges or other structures. This is not so with geotechnical and coastal engineers, who may also "feel" objects of their work, but their "feeling" follows from practical experience, which is obviously very important, rather than from ability to use new tools. Such modern tools should improve the craftsman's creative work, which must be remembered by theoreticians. KOLYMBAS [20] quotes the opinion of his friend that, "... it is normal if the avant-garde fails to be understood by a mass of 'customers' ". It is hard to dispute such a modest view, which probably follows from both erudition and experience.

In the case of mechanics of mixtures, one faces similar problems as those in soil plasticity, and it is hard to understand why, whilst more and more advanced models are created, engineers do not accept them and still apply simple, old methods. It seems that modern mixture theories have not shown their superiority in comparison with classical and much less complicated models. For example, if the production of an oil field can be increased by a few percent, due to the application of modern tools in analysing the extraction processes, it would mean that new tools are really better from the practical point of view. Such arguments would convince engineers to apply these methods, even if they are formally difficult. Note that the formal abilities are usually mastered on PhD or even more advanced levels. I have heard a story about an attempt to predict settlements of oil tanks using nonlinear consolidation models, when the experts completely failed because their predictions differed, by an order of magnitude, from the field measurements. Such results most certainly do not constitute good promotion for advanced applied science.

Applied mechanics have been deeply penetrated by concepts taken from the so-called rational mechanics, which notes both bright and dark sides. The bright side is educational, as engineers are better acquainted with such objects as tensors, invariants, etc. The darker side is that some researchers treat applied mechanics rather formally, not caring about the experimental and practical aspects of basic research. Some of them really believe that constitutive relations can be derived from general principles and aprioristic rules. Consequently, they review papers and research projects according to their philosophy, which often results in rejection of valuable contributions. Abuse of some dogmas is certainly not positive since it may retard real progress.

Unprofitable proportions between theoretical and experimental investigations must be changed, as this is a real world which should be analysed and described, and certainly not virtual nature. Therefore, researchers should always have in mind the end-users of their models, as well as the empirical verification of their theoretical concepts, at least on the laboratory level. Note that determination of such basic soil parameters as compressibility or permeability are not trivial, not to mention experimental determination of some constants appearing in the only ones to blame for lack of harmonious collaboration between research and engineering. An important element is also "a track-record which confirms the reliability of the predictions by comparing theory against monitored results from actual constructions", SIMPSON [40].

However, despite these defficiences, which should be gradually overcome, there are still problems which need fundamental research, within the framework of the mechanics of mixtures combined with soil plasticity. The already mentioned problem of static liquefaction is an example of such a challenge. The problem of pore pressure generation and liquefaction of saturated soils subjected to cyclic loads also needs further investigation and refinement, ISHIHARA [16], SAWICKI [29]. It should be noted that the recently coined general designation of "mechanics of porous media" maybe somehow misleading, because it suggests that porous media behave in a similar way. In fact, these materials behave very differently. For example, pore pressure and liquefaction happen in saturated granular soils, whilst these phenomena do not appear in saturated rocks.

Coastal engineering is a rich source of interesting problems which can be inspiring for applied mechanics, see SAWICKI [30, 34]. The sea coast is a highly complex and non linear system characterized by strong interactions between water waves and currents on the one side, and natural coast-lines, structures and sea bed on the other. Hydrodynamic phenomena are analysed within the framework of marine hydraulics, cf. DRUET [11], MASSEL [22], whilst other phenomena such as, for example, sediment transport or coastal and bottom changes, are studied using mostly empirical methods, but also applying some mechanics, cf. KACZMAREK [19], PRUSZAK [25]. Coastal sediments are two- or three-phase mixtures of the soil skeleton and pore water, the latter also containing some air. Such mixtures sometimes behave macroscopically like a solid body, and sometimes like fluids, and therefore the traditional division of applied mechanics on the mechanics of solids and fluids is irrelevant in this case.

Such problems as: sediment transport and sea bottom changes due to water waves and currents or interactions between water, structures and foundation soil are very interesting from the scientific point of view, and also important for practical reasons. They are very complex and therefore need interdisciplinary investigations, including continuum mechanics modelling. Coastal engineers can hardly compute the transport of huge masses of sediments along and across-shore, as they lack proper tools. Usually they use simple and very general balance relations to estimate macro-changes of the coastal zone in long-time scale. A spectacular example is the influence of the harbour in Władysławowo on the stability of the Hel Peninsula. A great amount of sediments had been deposited in this port, which had stopped a natural transport of this material. Therefore, the natural balance of this material has been disturbed, and the Hel shore should be supplemented artificially with sand, see BASIŃSKI *et al.* [4]. It would be interesting plemented artificially with sand, see BASIŃSKI *et al.* [4]. It would be interesting and useful to elaborate a continuum mechanics model of these phenomena. The list of scientifically interesting problems is long, but the problem is whether society, through respective authorities, would pay for such research. We cannot expect great scientific discoveries, but we are able to propose sensible research programs, which will lead to better understanding of processes appearing in the coastal zone, as well as to efficient tools enabling more rational management on the sea shore. Therefore, progress in both the coastal engineering and applied mechanics depends on social and economical factors.

6. INTELLIGENT BOTTOM PROTECTION IN HARBOURS

Opinions presented in the previous sections may sound too pesimistic for applied mechanics, as their role has been shown to be auxiliary rather than leading in the development of geotechnical and coastal engineering, but obviously there are exceptions from this rule. As an example, the case of inventing a new type of bottom protection in harbours will be described, cf. SAWICKI *et al.* [37]. This example illustrates how some knowledge of basic mechanics helps in designing of a structure which is better than the traditional ones. It is not an outstanding achievement, but the role of applied mechanics is also to tailor the *status quo*.

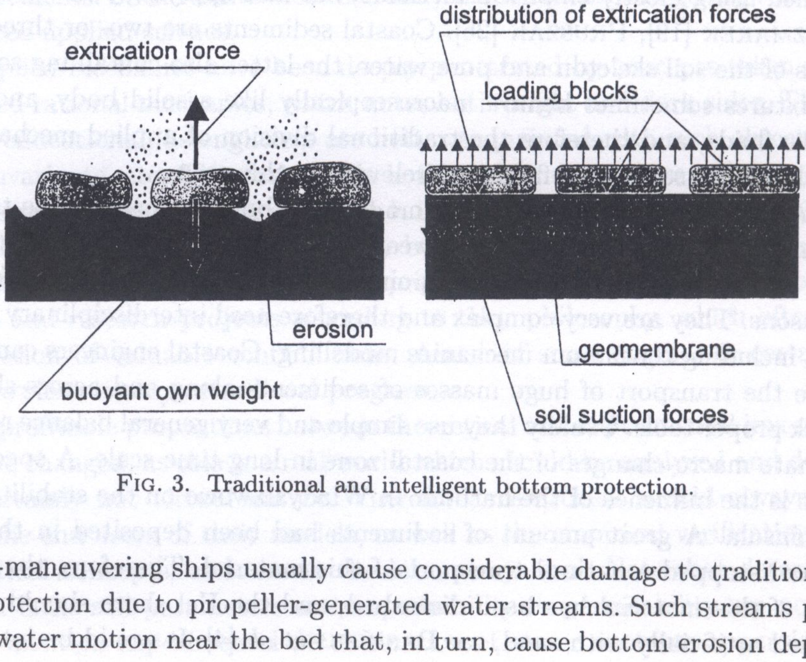

FIG. 3. Traditional and intelligent bottom protection.

Self-maneuvering ships usually cause considerable damage to traditional bottom protection due to propeller-generated water streams. Such streams produce strong water motion near the bed that, in turn, cause bottom erosion depending tect the beds, various technical solutions have been proposed as, for example, stones, sandbags, aqua sheets, etc. The design of these systems is based on the equilibrium of a protective element subjected to hydrodynamical forces caused by propeller-generated streams. Such stability analyses do not take into account interactions between the bottom protection and the subsoil, which results in heavy stone dimensions. Moreover, these water streams cause erosion of natural beds from spaces between particular elements of bottom protection. It has also happened that heavy stones caused serious damage to ships' propellers.

In order to prevent the above described phenomena and to make the bottom protection more efficient, a new type of this structure has been designed. The basic idea was to make this structure intelligent by making use of additional forces which are generated during extrication of objects from the saturated subsoil. A designation of the breakout phenomenon has been coined to describe the process which takes place during the extrication of objects from seabeds. During this process, soil suction forces between the object and the bottom are generated, the main result of this being that a force greater than a buoyant weight of the object is needed to extricate it from the seabed, cf. SAWICKI [31].

A new type of bottom protection consists of two basic elements. The first is a geomembrane (impermeable geosynthetic) placed directly on the channel bed. Its role is to protect against erosion. The second element constitutes loading blocks that have to be connected to the geomembrane. The submerged weight of the loading blocks should resist the extrication forces. During the extrication of the bottom protection, soil suction forces develop at the interface between the geomembrane and the subsoil. These forces are caused by negative pore water pressure during unloading of the subsoil. They depend on compressibilities of both the soil skeleton and the pore fluid. The soil suction forces, together with the submerged weight of loading blocks, resist the extrication force that, in turn, enables substantial reduction of the loading block dimensions. A new type of bottom protection was applied in practice in the Gdańsk Harbour.

7. CONCLUSIONS

This paper is probably not extremely original since similar questions harassed some other authors in the past, cf. GUDEHUS [13], MRÓZ [23]. Since that time (almost a generation!), no real progress in soil mechanics has been noticed, except for essential progress regarding available tools (electronics and informatics). Therefore, the main conclusions can be summarized as follows:

a. There exists a great gap between contemporary geotechnical/coastal engineering and applied mechanics, which develop almost independently. The role of applied sciences should be supportive for practical aspects of human activities by providing efficient tools which would enable more rational designing of various objects.

b. Engineers prefer traditional and simple methods which seem to be sufficiently good for practical purposes. Advanced mechanical models of materials and processes have not been accepted as engineering standards for certain reasons. Namely, these models are formally very difficult, their parameters are also difficult to determine, even in laboratory conditions, and most of the models have not passed empirical verification tests. Moreover, it is hard to find practical examples showing the superiority of new models against the traditional methods.

c. There is a large number of interesting problems which could be inspiring for applied mechanics investigations. The problem is whether society wishes to pay for such research. These problems include basic investigations on deformability of soils, liquefaction of soils, soil dynamics, interactions between water, soil and structures, dynamics of coastal zone and sea bottom, sediment transport, etc. The role of applied mechanics in the progress of civil engineering should be more auxiliary than leading, as it has been so far. One cannot expect new discoveries, but rather refinement and tailoring of the existing knowledge.

d. It is difficult to propose new research directions in soil mechanics, as it could be associated with a kind of central planning. However, in order to make the most of the available resources (people and their knowledge and skills), some targets should be identified, see SAWICKI [32, 33]). It seems that the main target should be elaboration of a reliable engineering model enabling estimation of pre-failure strains in soils, which could replace the existing methods, based mainly on elasticity theory. Firstly, a rigorous examination of existing theories against experimental data should be performed in order to select the best models. Different authors have their own visions, see BOLTON [6], GUDEHUS [13], KOLYMBAS [20], MRÓZ [23], and such a competition would be valuable. I hope that the winner will present a model which would be as simple and attractive as the models applied in contemporary structural mechanics and strength of materials.

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