La formation de l'ingénieur hydraulicien aujourd'hui

TABLE RONDE

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La place des mathématiques dans la formation de l'ingénieur hydraulicien

1. Introduction

Parler des mathématiques dans la formation de l'ingénieur hydraulicien comporterait, à mon avis, deux dangers : ou bien entrer dans les détails des programmes d'enseignement des mathématiques dans les Ecoles d'Ingénieurs ou alors discuter de la philosophie des mathématiques. Dans le premier cas, le risque serait de retrouver un contenu de mathématiques universel, le même dans les Universités aussi bien des pays de l'Est que de l'Ouest. Dans le second cas, on resterait plutôt à un niveau théorique et abstrait, peu utile pour le débat de ces Journées.

Pour ma part, je vais tout d'abord essayer de préciser les avantages mais aussi les pièges possibles lorsqu'on utilise les mathématiques dans le domaine des Sciences et Techniques de l'Eau. Ce sera le débat entre l'empirisme et la stylisation mathématique ou entre le pragmatisme et la théorie. Les hydrauliciens sont d'ailleurs bien placés pour apprécier les paradoxes hydrodynamiques lorsqu'on entre dans les applications pratiques.

Ensuite, je vais essayer d'analyser le fait que le niveau et le contenu des mathématiques qui entrent dans le métier de l'ingénieur ne sont pas immuables. Ils varient dans le temps en fonction du progrès enregistré dans la science des mathématiques, de l'évolution de la technologie informatique, des problèmes posés par la société et de l'attitude des ingénieurs face à ces problèmes. Ceci nous amènera vers la pédagogie des mathématiques dans les Ecoles d'Ingénieurs autant du point de vue des programmes que du point de vue de la formation de l'esprit de l'ingénieur hydraulicien.

2. Empirisme et mathématiques

Il n'est pas aujourd'hui concevable d'imaginer un ingénieur hydraulicien qui n'utiliserait pas de manière régulière les mathématiques dans son travail. Du calcul des courbes de remous à l'aide des équations différentielles à la résolution des équations aux dérivées partielles de Navier-Stokes, les mathématiques sont bel et bien implantées dans le métier de l'ingénieur hydraulicien. Dans un monde où dominent aujourd'hui les techniques informatiques, les mathématiques entrent de plus en plus dans l'exercice et le développement de l'hydraulique. Cette évolution est d'ailleurs tout à fait dans le courant du développement moderne des Sciences de l'Ingénieur, qui profitent de plus en plus du progrès des mathématiques.

La stylisation mathématique des phénomènes physiques est bien sûr l'étape indispensable de la démarche scientifique, qui suit celle de l'observation des phénomènes naturels. A la description qualitative des « faits » vient le besoin d'une « explication » des mécanismes fondamentaux (modélisation) ainsi que d'une « quantification » des grandeurs physiques. Cette formulation mathématique est d'ailleurs indispensable à l'ingénieur dont l'objectif est de prévoir l'évolution future et de calculer son ouvrage.

Nous pouvons concevoir l'évolution des mathématiques pures et appliquées d'un côté, et celle des Sciences de l'Ingénieur de l'autre, en deux courants parallèles, ayant maintes interconnexions entre eux. En fait, beaucoup de progrès dans la connaissance des phénomènes hydrauliques ont pu profité du progrès enregistré en mathématiques et vice-versa. La théorie des fonctions analytiques de Cauchy a par exemple permis le calcul des écoulements autour des profils d'ailes. D'un autre côté, nous pouvons peut-être penser à la théorie du calcul différentiel, lorsque Aristote, parlant dans son œuvre « métaphysique » de la représentation du monde physique, affirmait « qu'on pouvait poser comme séparé ce qui n'est pas séparé ».

Le caractère abstrait des mathématiques et la puissance des micro-ordinateurs modernes pour simuler les phénomènes physiques donnent à penser à la supériorité de l'approche mathématique sur l'empirisme. Cependant, les paradoxes hydrodynamiques sont là pour nous rappeler des dangers d'un emploi abusif de l'outil mathématique. Les solutions mathématiques élégantes basées sur les fonctions analytiques de Cauchy conduisent à la conclusion que l'aile d'un avion ne décollerait pas, tant que la viscosité du fluide est négligée. D'autre part, les simulations mathématiques sur ordinateur peuvent paraître comme jeux de l'écran, lorsque la validation expérimentale est absente. La relation dialectique entre les mathématiques et la réalité doit donc être prise en compte dans la pédagogie des mathématiques de l'ingénieur.

3. Pédagogie des mathématiques

A la question quelles mathématiques doit-on enseigner dans les Ecoles d'Ingénieurs, il y a bien sûr plusieurs réponses. Toutes doivent tenir compte de ce que l'on attend d'un ingénieur et de ce qu'est son rôle dans la société. La question est souvent sujette à maints malentendus et se heurte à certains privilèges sociaux établis. Ainsi un ingénieur peut être :

a) un scientifique : qu'est-ce qu'il le différencie alors des autres scientifiques, comme des mathématiciens, des physiciens ou des chimistes ?

b) un technocrate : dans ce cas, se pose la question comment le situer par rapport aux autres techniciens supérieurs.

c) un mandarin, qui utilise son diplôme pour protéger sa place dans la société.

Nous pouvons dire qu'un ingénieur doit maîtriser la culture scientifique afin de résoudre, par son expérience, les nouveaux problèmes posés par la société. Son rôle n'est pas de s'occuper des problèmes ayant des solutions stéréotypées, mais d'utiliser le progrès technologique afin de résoudre des problèmes originaux. La réponse à ceux qui voient dans la pédagogie des mathématiques de l'ingénieur la perspective d'utiliser seulement des tables d'intégration est alors simple : plus que cela, un ingénieur doit se familiariser aux constructions mathématiques et aux développements modernes de cette science afin qu'il soit apte à réagir aux situations imprévues. Savoir poser les problèmes, faire les hypothèses et simplifications nécessaires pour formuler et ensuite calculer cette solution, telle est la démarche propre à la culture mathématique.

4. Conclusion

Entre l'utilisation des tables d'intégration et les mathématiques purement abstraites, l'ingénieur hydraulicien doit avoir une culture mathématique de haut niveau. Plus qu'un outil pour résoudre les problèmes d'intérêt pratique, la culture mathématique peut jouer un rôle dans la formation des esprits novateurs. La complexité de l'outil mathématique et ses utilisations est bien sûr fonction des développements propres à la science mathématique et aux techniques informatiques. Toutefois, plusieurs paradoxes hydrodynamiques sont de bons exemples pour démontrer les dangers d'une utilisation abusive des mathématiques dans le monde réel de l'ingénieur hydraulicien.

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The hydraulic teaching in Spain and its future

1. Introduction

The fact of Spain being a country with almost no tradition in the Hydraulic Engineering field is, with no doubt, consequence of the small activity developed by the University in this area. In fact, the number of professors devoted to this discipline, with full dedication, was almost nonexistent.

Nevertheless, this situation was not due to a lack of vocations or talent, but to low salaries and to an absence of competitivity and impoverishment. Then, the final result could not be another one : the best qualified professionals took the industry option and, in cases of a strong teaching vocation, they dedicated few hours to University activities.

The loss of a creative lead, typical of the University's activity and the practical absence of R + D sections in the Consultances and Industries of our country, due to a more profitable acquisition of foreign technology, had conducted to an nonexistent creativity in the Hydraulic Engineering field. A direct consequence has been the really small number of quality books and articles written by Spanish authors during the last fifty years.

In 1983 the University Reform Law (LRU) is promulgated by the first Socialist Government. This fact will allow an important change in the University's situation. The LRU will improve the salaries, but also will permit the cooperation between the teams compromised in R + D with the Industry and the Administration. The money generated by this cooperation is almost totally inverted in the group that has developed the work and then the salaries may be complemented, personal support may be hired, and laboratories, libraires and computer centres infrastructure may be improved.

On the other hand, the amount of money devoted by the Administration to support research projects of competitive groups, has also been raised during the last years. This has allowed the take off of the new teams.

Nevertheless, the LRU has not solved all the problems for the University-Nobody controlls the real dedication, competitivity and orientation of the teaching statement, but it can not be denied that the ways to accomplish a much more rewarding work at the University are already stablished for those who want to develop such an effort.

In brief, we have now an acceptable situation to encourage, from the University, the development of the Hydraulic Engineering, and we believe that with regard to our colleagues of the EEC developed countries we have the disadvantage of an almost total lack of tradition. But, on the other hand, the works or developments that may be accomplished can also lead to more spectacular results, because the starting reference levels are low. The repercussion that they may finally have in Latin America will contribute through the years to increase the importance of this contributions.

2. Actual situation of hydraulic education in Spain

The catalogue of Engineering careers in Spain is very old, and besides the actual Study Plans date from 1964. This brings us an immediate and most negative consequence, a lack of adaptation in titles and subjects to the new technologies that have been widely developed through the last years.

The Educational Ministry, aware of the problem, made in the last three years a considerable effort in order to enlarge the catalogue of titles and also trying a deeply reform of the study Plans. Nevertheless, in the beginning of this year, and when the project was already quite advanced, it suffered a sudden stop. The five reasons that, in our opinion, have led to this are :

a) An important additional cost in a moment with a great public debt. Besides the actual economical situation is not as good as it was when the project started.

b) Lack of agreement between most of the Universities involved in developing the new curricula.

c) Vested interests existent between professional collectives in active.

d) An inoperative procedure.

d) Political reasons, after the initial strong disapproval detected in the first operated changes.

Consequently the enlargement and reform of the curricula Engineering titles has been postponed « some die ». Our study plans, which are 25 years old, envisage a wide basic education and a small specialization, due to time limitations even thought engineering studies in Spain are longer than the average, reaching six years in the majority of the cases.

The traditional arguments in our country about a greater specialization instead of a basic formation are, in fact, presided by the characteristics of the Spanish Industry, mainly of services and in any case with a poor research tradition. By the other hand the market regulation is given by the supply and demand, and the conversion of a generalist engineer to an specialist must be done easily by the same industry. Then, the supporters of a wide general education are majority although at the University there are discrepancies from this simplistic point of view. For the Educational Ministry a wide basic education has an undoubtedly lesser economic cost from the teachers point of view as well as the laboratory equipment me. So the Administration is compliant with such a situation.

Immersed in this general context, few are the possibilities to have in Spain an hydraulic engineer as in other EEC countries. In fact, in the by the moment paralyzed titles catalogue, the hydraulic engineer one had few support. But, in any case, only time knows what futures will bring, and so we will describe the actual situation.

Among the studies in use in Spain, hydraulic is included in the next five Engineering Curricula : Agricultural, Civil, Industrial, Mines and Naval. The one with a greater specific weight is, from our point of view, the Civil Engineering (in Spain is called Roads, channels and Harbours Engineering). This curriculum has an Hydraulic and Energetic speciality which contains study of the following subjects : Hydraulic, Hydrology, Water Resources, Hydraulic constructions and Coastal Engineering between many others.

The other four curricula emphasize on their own hydraulics aspects :

— Agricultural : Irrigation and drainage.
— Industrial : Machinery and hydroelectric power stations.
— Mines : Hydrogeology.
— Naval : Maritime Hydraulic.

We can conclude pointing out that the teacher has some skills to improve the pedagogic techniques and the contents, but always inside the framework of a very old study Plan. Our University, sensitive to these problems has stablished a Plan for innovation in education (PIE) that firmly suports the people whih such inquietudes.

3. The University reform law (LRU) and the new departments

We have already refered to the importance that, in our opinion, has had the LRU, allowing more competitivity and incentives to the active teams. But another important aspect has been the possibility to promote new Departments grouped by fields of interest, no matter in which Engineering School the teaching is made. In our particular case, all the teachers involved in Hydraulic Engineering of our University has been collected in the same Department. The Department must organize and develop the research and also to stablish the final programs to be teached to their students in the Hydraulic field.

With this new conception, Spanish Universities, traditionally organized in Schools of Faculties, become articulated in Departments, what seems much more logical from the teaching and research point of view.

This reform, very deep according to the law's spirit but not so important considering its subsequent development, has allowed in our case the creation of a Hydraulic and Environmental Engineering Department with an undoubtedly superior potential that the one we had before as isolated teams. It has been for us an extremely positive reform.

Seven are the Departments in Spain that include the Hydraulic Engineering area, sometimes with additional fields inside them. They are :

— Departamento de Ciencias y Técnicas del agua y del medio ambiente (Universidad de Cantabria),
— Departamento de Agronomía (Universidad de Córdoba),
— Departamento de Ingeniería Hidráulica, Marítima y Ambiental (Universidad Politécnica de Cataluña),
— Departamento de Ingeniería Civil y Ordenación del Territorio, Urbanismo y Medio Ambiente. (Universidad Politécnica de Madrid),
— Departamento de Ingeniería Hidráulica y Energética (Universidad Politécnica de Madrid),
— Departamento de Ingeniería Hidráulica y Medio Ambiente (Universidad Politécnica de Valencia),
— Departamento de Mecánica Aplicada e Ingeniería Térmica (Universidad de Valladolid), although in this last case, the presence of the Hydraulic Engineering seems week.

The new Departments are now five years old an their particular results are quite different. In fact, adaptation problems, physical distance between teachers belonging to different schools, or different ways to see the University between the involved groups have limited the results.

4. Post-graduate courses and masters in the hydraulic engineering field

The fact that the continuous evolution of the Society and its technological needs has been much faster that the evolution of the University, justifies the increasing number of Post-graduated courses and a Master degree in Hydrology and water management with two options : water resources and urban water management. In a future Agricultural Hydraulic could also be considered.

The need of courses and masters will be higher with no doubt, since technology is in progress while the available Engineering curricula remain blocked. On the other hand, as it has been pointed out, the study Plans do not allow to develop adequately the contents of the different subjects to the actual needs.

We also believe that, with the coming free EEC market, the importance of a permanent update will grow up continuously due to two important reasons :

a) A stronger competence on the part of the engineers coming from more developed countries.

b) The corporatism between the different kind of engineers, has stablished their working fields with little common sense. This stablishment will come down when Spanish structures become more similar to the European ones. This will allow a valuation based on the real knowledge instead of a pre-assigned area, like it should be happening right now.

Then, the future of contrasted masters and post-graduate courses, no matter who promotes them (University, Administration, Consultances, etc...) is encouraging as a consequence of the each time greater distance between a rigid official offer in curricula and the need of an uptated on specific subjects. That should explain the great number of them, even though in some occasions the level does not reach the standard needed.

5. The use of computers and numerical models in the hydraulic engineering field

The engineering studies in Spain don't allow to include inside the Hydraulic items this subject deeply enough. Consequently, when the professional needs these tools later on his career they may be even unknown for him.

On the other hand, the future of the numerical models applied to the resolution of certain Engineering problems is tremendous, since a personal computer can be afforded by a medium class family. Consequently they are much cheaper than the physic models, that only big laboratories can afford.

The lack of knowledge about the real possibilities of those skills their great utility and the easy access that the engineer has to them, open to us from our point of view of Hydraulic's teachers an important challenge. The use of the numerical models in hydraulic is not only a matter of important Consultances and Administration but also for engineers of medium and small towns, and for anybody who needs to do a complex hydraulic analysis.

But the use of adequate and Commercial software has some important restrictions. First at all it must be kindly, easy to use and with a high reliability. And secondly, a physical and mathematical knowledge of the problem is needed for the person who is using the program. Only in this way he is able to analyze if the data are correct and if the results are coherent with them. When the solutions, with their corresponding investments, are considered the rool of the engineer is essential. By this reason, sometimes, the use of powerful computer tools by people with no knowledge of mathemtical and physical background is dangerous.

The teaching of these techniques in our country must bed one in post-graduated courses, seminars or masters. On the other hand, we cannot forget our responsibility spreading and advising about the use of these tools through specialized magazines and books. The University must extend its labor further away than the expedition of titles, if it really wants to be useful to the Society.

The availability of solftware created by foreign Universities and Institutes cannot be forgotten, although its use may present important limitations :

a) Its existence can hardly be know by most of the professionals that could feel the need of using it.

b) The problem of a different language, although it can be solved in part by translating the software, becomes serious drawback when the user finds an specific problem and the authors or responsibles for the program are for away and speak a different language.

c) All the programs, for a correct use, need a wide knowledge of their mathematical and physical background.

Although all these troubles can be overcomed by an adequate marketing, we think that we must work in Spain in the development of our own software, without forgetting the existence of the one coming from abroad. Only in this way, we will be able to incorporate to that software the last developments achieved. Besides a deep knowledge of these tools will allow us to its better use and application. We will also feel much more motivated to widely spread its use.

Another interesting way of work is the adaptation of software developed abroad to our reality. For example the treatment of our hydrological series may be different to the one applied in Northern Europe, the design parameters, data base, etc..., can be different. But, in any case, to follow this policy creates a total and permanent dependency, what supposes along the time a serious limitation.

The same conclusions that we obtained in the introduction when we spoked about our University can be extended here when we are referring to the mathematical modelizations of hydraulic problems. We said before that with reasonable developments we can obtain important results, due to the great impact and level of approval that in short time could have. This is, with no doubt, what also stimulates groups of Universities like Barcelona, Cantabria, Madrid, etc..., strongly compromised with the mathematic modelization of different hydraulic problems.

Conclusions

Teaching Hydraulic is Spain, like another branches in Engineering, is becoming difficult since the study plans are old fashioned and the new Engineering curricula, has been suddently stopped, although it would'nt have contained Hydraulic Engineering.

On the other hand, since the promulgation of the LRU in 1983, Spanish university has begun to recover from a non-creative period. New ways have been created to allow competitive teams to take off towards R + D projects.

To attend the needs of formation for professionals, the post-graduated courses, seminars and masters have shown themselves as a very efficient way, allowing at the time the divulgation of new technologies and the recovering of the generalistic education with specific topics.

Our EEC integration, also in education, has begun to generate results through programs like Erasmus, Lingua, Cost, Comett, and now Tempus. All of this is allowing an ideas exchange highly profitable. A good sample of our superior participation is the fact of International Congresses, Meetings or Conferences taking place in our Country, in the Hydraulic field, is becoming something frequent.

Finally, the utility, reliability and low cost required by the mathematical models of hydraulic systems make them to preferred by the hydraulic teams of the different Universities.

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La valeur et la place de l'expérimentation en laboratoire et en site industriel

Déjà au XV^e siècle, Léonardo da Vinci proclamait que « Toute étude de l'eau devait nécessairement commencer par l'expérimentation ». Trois siècles plus tard, d'Alembert confirmait que « La théorie des fluides doit avoir nécessairement pour base l'expérience ».

En dépit de l'ère informatique, ces proclamations n'ont, aujourd'hui, rien perdu de leur valeur. Au contraire, les modèles de simulation numérique qui semblent s'être imposé l'impossible tâche de supplanter les modèles physiques ont également besoin de résultats expérimentaux. En effet, tout modèle numérique non vérifié et calibré par l'expérimentation n'a aucune chance de survie.

Généralement, l'expérimentation en laboratoire hydraulique, c'est-à-dire sous des conditions reproductibles, est nécessaire lorsqu'il s'agit :

— d'étudier des phénomènes complexes dont la description n'est pas accessible au calcul (érosion, affouillement, turbulence, entraînement d'air, transport de sédiments, etc...) ;
— de vérifier ou de corriger des théories ;
— de calibrer des modèles de simulation numérique ;
— de développer des techniques de mesures.

Par contre, l'expérimentation *in-situ* est particulièrement nécessaire lorsqu'il s'agit :

— de vérifier les lois de similitude et de quantifier des effets d'échelles éventuels ;
— de calibrer un modèle physique (calibration hydraulique, sédimentologique, etc.) ;
— de surveiller des ouvrages ou installations industrielles (instrumentation de barrages, d'ouvrages maritimes, etc.) ;
— de collecter des mesures de grandeurs souvent aléatoires (houle, vent, courants, précipitations, etc.) en vue de l'élaboration d'une banque de données statistiques qui permettra un calcul de risque et une conception probabilistique plus fiables des installations et ouvrages hydrauliques.

D'une manière générale, la valeur de l'expérimentation est de réduire les coûts ou les risques des ouvrages ou installations. Toutefois, le bénéfice résultant directement de l'expérimentation ne peut, très souvent, pas être évalué d'avance. Ce qui est rare, par contre, c'est qu'une étude expérimentale ne provoque pas de modifications dans la conception des ouvrages ou installations prévus initialement.

Un exemple de l'étude des résultats de 50 modèles réduits portuaires illustre les effets de l'expérimentation sur les coûts probables des projets *(tabl. 1)* :

En résumé, on peut dire que l'expérimentation est particuliairement bénéfique lorsque :

— le type d'installation conçu on construit est nouveau et important ;
— il n'existe pas de solutions alternatives fiables d'étude (modèle mathématique ou numérique) ;
— tous les facteurs d'influence et leur action ne sont pas encore bien connus. (Exemple : action combinée de la houle, des vents et des courants sur le transport des sédiments, vu que cette action est si complexe que seul l'expérimentation en laboratoire complétée par des mesures in-situ est capable de prévoir les effets des ouvrages maritimes).
— la visualisation des phénomènes est d'une grande importance. La conception de grands ouvrages tels que barrages, ports, etc. est souvent le résultat d'un compromis entre ingénieurs, aménageurs, financiers, etc... Il est évident que l'aboutissement d'un tel compromis est plus aisé autour d'un modèle réduit représentant tous les aspects de l'aménagement réel.

Pour conclure, on peut dire que même au-delà l'an 2000, l'expérimentation en hydraulique ne perdera rien de sa valeur actuelle.

Tableau 1. Effets des études sur modèle réduit sur les coûts de projets portuaires [1]

Effets sur le projet	Modèle de houle	Modèle de marée
Réduction des coûts	5 %	—
Amélioration de la conception à faibles coûts	30 %	75 %
Aucune modification	3 %	8 %
Réduction des risques et augmentation des coûts	62 %	17 %
Nombre d'études	38	12

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The place and role of experimental works in the laboratory and in industrial sites - the case of hydraulics education in Sweden

Introduction

This paper deals with the current status of the place and role of experimental works in the hydraulic education of students for the degree of civil engineer in Sweden. The contents of the paper refer to the conditions and views at the Faculty of Civil Engineering at three different Swedish Technical Universities — in Stockholm, Gothenburg and Lund — with a total yearly intake of approximately 300 students. These three universities are the main centers for basic and advanced education in hydraulic engineering and should thus be representative of the situation in Sweden. The information is based on my own experience as a lecturer in hydraulics in Lund for 15 years and on interviews with lecturers in charge with the hydraulic education at the other two universities.

In order to put the experimental works into a perspective the paper will start with a brief overview of the education of civil engineers in Sweden with a special emphasis on the hydraulic part. Then the ways of integrating experimental work into the hydraulic education and the purposes of the work will be discussed in a more general manner. After that a more detailed description of the experimental work — mainly as laboratory exercices — will be given including the types of exercises, the carrying out and reports of the exercises, views of the students, problems. Finally some conclusions and desires will be discussed.

Hydraulic education in Sweden

The curriculum at the Faculty of Civil Engineering comprises four years of studies. The way of organizing the courses differs somewhat between the universities. The first two or three years consist of compulsory studies of more basic nature and common to all civil engineering students. During the last one or two years the students can make a choice from a large number of courses in order to specialize in certain areas (a certain amount of courses are needed in order to get the required number of credit points). The way of choosing courses has been controlled in different ways through the years. The courses have been gathered into 4-5 groups or fields of specialization such as construction, water resources engineering, management and the students had to choose one such group and study all the courses of that particular group (plus a number of other courses at their own will). At other times the students have been free to choose whatever combinations of courses (although some restrictions exist) they wanted. This latter policy is prevalent in Sweden today (except in Gothenburg). The students also have to fulfil a Master Thesis work, comprising 400 h of studies, of theoretical, experimental or field nature on a specialized subject.

In the context one could mention that a major revision of the education took place in Lund four to five years ago with the aim to make the civil engineering education more generally applicable. This has led to, among other things :

— stronger emphasis on basic courses. Thus there are three years of compulsory studies ;
— the use of English textbooks as far as possible ;
— cooperation with other technical universities in Europe implying that students can spend their fourth year at a foreign faculty in order to get a more comprehensive education in a certain field and to learn a foreign language and get acquainted with a different culture. Thus there is an ongoing cooperation with Zurich, Paris, Karlsruhe.

All students take a basic course in hydraulics during the second (Gothenburg) or the third year (Lund, Stockholm). The contents and extent of this course vary somewhat between the different universities although the structure is the same — i.e. lectures, solution of problems, laboratory exercises. Thus the present situation is shown in the table below.

The relatively favourable situation in Lund is a result of the major revision mentioned before and is an expression for the increased emphasis on basic understanding — in this case on water flow phenomena. Very briefly the hydraulics course in Lund deals with :

— hydrostatics,
— properties of water,
— laminar and turbulent flow,
— basic equations (cont, mom, energy),
— pipe flow,
— pumps,
— open channel flow,
— boundary layers and flow resistance,
— similitude,
— measurement devices,
— hydraulic components and structures,
— water power plants.

As the allotted time is smaller at the other universities some parts are excluded (for instance open channel flow in Stockholm) and/or lesser amount of time is devoted to each part. It should be added that Gothenburg takes up groundwater flow as well.

On top of the basic course a number of hydraulic courses (continuation or advanced courses) could be studied by choice

Place	Lectures (h)	Problems (h)	Lab (h)	Course duration (weeks)
Lund	56	56	4	14
Gothenburg	28	26	6	7
Stockholm	----- 36 -----		4	7

during the third or the fourth year. There is a certain difference between the universities as to the direction of these courses — either given by tradition or research interests :

Lund :	Costal engineering and recipient hydraulics, hydraulic transients (not now), urban hydrology, groundwater technology.
Gothenburg :	Offshore technology, coastal engineering and recipient hydraulics, hydraulic transients.
Stockholm :	Open channel flow, water power and port engineering, dam construction.

Generally speaking one might say that hydraulics is a relatively minor area in the Swedish civil engineering education. Thus it is not possible to obtain a comprehensive coverage of the hydraulic field during the four years of study — i.e. one can not solely specialize in hydraulics. Attempts to organize a specialization have comprised courses in hydraulics, hydrology, sanitary engineering and geology covering approximately half the number of the required number of credit points.

Experimental work in hydraulic studies - general situation

Experimental works can enter the hydraulic education in different ways. As the table above shows the basic course in hydraulics at the different universities in Sweden contains a small laboratory part with active, experimental work, compulsory for each student, with a duration of 4-6 h per student. This work is directly attached to the contents of the course and is carried out in concentrated (in time) form during the duration of the basic course on existing, ready-to-use experimental set-ups in the laboratory. This laboratory work must be carried out in an approved manner before the student gets the credit points for the course. The general tendency is that the extent of this kind of experimental work has diminished through the years — mainly because it is a rather time-consuming (i.e. expensive) educational activity from a teacher resources point of view. Thus the allotted time for each student in Lund used to be 8 h whereas it is now only 4 h. Gothenburg, on the other hand, has devoted the same amount of time, 6 h, to laboratory work for a long time.

The purpose of this laboratory work is actually not always explicitly written down although the work is important from a number of points of view. The foremost purpose — as emphasized at all three universities — is to illustrate water flow phenomena and some basic laws and to transfer a feeling for the way water behaves in different flow situations. This is all the more important as the students are used to the mechanics of solid bodies before they begin their hydraulic studies. One example concerns the hydraulic jump which is difficult to explain convincingly at the blackboard but which is very rewarding to show in the laboratory. Other views on the importance of laboratory studies in the basic course are :

— experimental work will transfer the impression that water flows are complex and that hydraulic calculations are subject to uncertainties. One example is given by the measurement of a discharge using Thomson weir. Another example is given by the hydraulic jump which in theory looks very nice with a smooth downstream water surface and a nice, two-dimensional transition. This feeling for the inaccuracy in hydraulic calculations and measurements is all the more important to transfer these days when the minicalculator or the personal computer have such widespread use and which might give a false sense of accuracy ;

— experimental work can give some information on measurement methods for pressure, flow, stages etc. ;

— experimental work can give an impression of the size of energy losses in different flow situations and how visually small changes in the flow geometry can change the loss significantly — for instance the difference between a smooth and a sharp entry into a pipe ;

— at one university the report of the experimental work and the results is carried out as an exercise in oral presentation which certainly needs practicing. One could add that Lund has special courses for such things.

The continuation courses do also sometimes contain experimental parts but not in such a formal manner as goes for the basic course. One exception concerns a 30 h course in Stockholm on open channel flow and discharge structures which involves a 4 h laboratory exercise for each student. Otherwise the experimental works tend to be of a more demonstrational character on such items as pressure transients, surge shafts, wave forces, stratified flows, jets. Sometimes existing physical models are used for demonstrating flow phenomena or for a comparison between measurements and calculations. Thus harbour models have been used for showing refraction and diffraction, models of river stretches with bridge piers have been used for a comparison between calculated and measured water levels.

Field visits to hydraulic works do sometimes take place within the framework of an advanced course. However, such visits — to hydropower plants, dams — are also of a demonstrational character.

The second possibility for the students to be engaged in experimental work is given by the requirement of each student to carry out a Master Thesis work during the end of the studies — i.e. normally during the fourth year (or later), in order to study a problem thoroughly and more or less independently and present the work in a report. The total time devoted to the work should not be less than 400 h. The work could be of theoretical, experimental or field nature. Normally the students are free to choose the subject and area of their work — i.e. it need not be in hydraulics. However, if formal directions of specialization exist (water resources engineering for instance) the student has to choose a Master Thesis work within his choice of direction. As there is no policy now of designing the Master Thesis works in any special fashion the works can be of very different characters. Thus one could notice that the interest in purely experimental work in the laboratory is diminishing — Stockholm reports for instance that they have got such a laboratory Master Thesis work once every second year on the average. As examples of experimental laboratory work in Lund one could mention :

— study of the hydraulics of mixers for flow generation in channels ;

— study of transient free surface/closed conduit flow in pipes in conjunction with the use of sewage water for heat pumps ;

— study of the stability of a layer of freshwater on top of a saltwater layer in conjunction with the development of a new method for the storage of freshwater.

Such works seem to be very useful for the students as they get acquainted with the planning and design of an experimental set-up, with measurement techniques and their inaccuracies and also the problem of interpreting the results. It is also possible to integrate computer applications (popular among students) in such works — for instance through data collection and comparative computations.

However, as stated above, the interest in such experimental work is diminishing. One area of growing interest is of course more computer-oriented applications — developing algorithms and/or applying already existing ones. Another type which is becoming very popular concerns field studies in developing countries in cooperation with Swedish agencies for development aid — feasibility studies of small-scale hydropower plants, dams, use of sewage water for irrigation.

Laboratory exercises - details

Each student works with laboratory experiments for a minor part of the basic course — typically of the order of 4-6 h each. The exercises are generally run in a concentrated form during 2-3 weeks during the latter part of the course. This means that some parts of the course have not been studied at the time for the exercises, i.e. the students will lack the theoretical background for these particular parts thus diminishing the understanding of the exercise. This is of course and obvious drawback but it is difficult to do it in another way when the total duration of the course is only 7 weeks. The conditions are more favourable for the more extended Lund-course.

The exercises consist of 4-6 different studies on experimental set-ups which are ready to use. Each experiment should last for about an hour. As examples of studies one could mention :

— Laminar and turbulent flow in pipes. Determination of the frictional coefficient in the different cases. Flow visualization.
— Energy losses in pipe flow — frictional and local losses.
— Equation of momentum using a set-up producing a vertical jet lifting a weight.
— Discharge from different kinds of orifices — determination of μ-values.
— Visualization of flow around bodies, flow at inlets, separation.
— Determination of pump curves for different rotational speeds.
— Hydrodynamic flow resistance — measurement of forces for bodies of different shapes.
— Flow over a smooth-crested weir — determination of the discharge coefficient.
— Study of a hydraulic jump and verification of its formula.
— Groundwater flow under a dam. Effect of drainage, grooved piles etc. Hele-Shaw apparatus. Flow visualization.

The exercises consit typically of some simple measurements of flows, pressures, depths, forces and checking with formulas such as the energy equation, equation of momentum, equation for hydraulic jump, the equation for flow resistance, discharge formulas, equation for gradually varied channel flow.

The exercises are carried out in groupes of students (i.e. one group carries out one study at a time). At each occasion (2-4 h) a number of groups circulates among the different set-ups. This means that each student will pass 4-6 h in the laboratory during one or two occasions. The situation at the different universities is shown in the table below.

The students get a manual describing some theory, the set-up and how the exercise should be carried out. The way the students have prepared themselves for the exercise is not formally checked but an assistant is briefly introducing the exercises and is then supervising the work.

The results are reported either in written form (using the manuals and not involving much writting — mainly reporting the measurements) and in one case orally. These reports are compulsory and should be approved of before a student has passed the course. The oral presentation is done with 6 students at the same time during 120 min. Each student should present one exercise during 5 min and he will also get some questions on the other exercises. Comments are given immediately by the assistant.

Some non-systematic investigations indicate that the students consider the exercises to be a valuable part of the course — one inquiry showed that 6 students were not satisfied, 13 said it was OK and 19 said that the exercises were good.

There are of course problems too attached to the exercises. Some views that have been put forward by students and teachers are :

— the exercises should not precede the lecturing on the specific subject,
— there is a risk that the students get concentrated on the handling of the apparatus in a set-up so that they would miss the essence of the exercise,
— the tight time schedule means that the manuals are rather detailed implying that a student could carry out an exercise without really knowing what he is doing.

One general impression is also that the students rather often seem to be lacking experience in carrying out physical experiments.

Discussion and conclusion

It is evident that experimental works do not play a very significant role in the basic education in hydraulics in Sweden. The main purpose of experimental works seems to be to illustrate hydraulic phenomena and to transfer a feeling for the way water behaves. The reason for the modest role is probably a combination of tradition and lack of resources. However, experimental works could be important from a number of points such as getting acquainted with measurement techniques, obtaining a feeling for the degree of accuracy with which hydraulic computations could be carried out, increasing the experimental ability of the students, in general increasing the understanding of hydraulics. Thus an increased element of experimental works should be valuable. There are at least two possible ways of accomplishing this. As for the basic courses in hydraulics more experimental works most probably imply a demand for more teaching resources. It is, however, difficult to increase the amount of experimental works within the time span of such courses, typically seven weeks. One possibility might be to create a special laboratory course in hydraulics which should be studied immediately after the more theoretical course has been finished. When changing and/or increasing the amount of experimental works one should consider making them less arranged and stress measurement techniques and the use of standard equipment.

The second possibility would be to direct the Master Thesis work in such a way that more experimental work had to be carried out. This proposal has the advantage of not requiring more teaching hours formally. The disadvantage is of course that not all students will participate.

	Group size	Nr of groups simultaneously	Nr of occas.	Time each occasion (h)	Total nr of set-ups
Lund	3	4	2	2	4
Gothenburg	3	3	2	3	6
Stockholm	3	5	1	4	5

Prof. P. Henry, IMHEF-EPFL (Suisse)

L'importance accordée à la technologie

La définition d'un « Ingénieur hydraulicien » est difficile à énoncer. En réalité, il s'agit d'un *spécialiste en mécanique des fluides,* incompressibles comme le suggère le terme « hydraulicien », ce spécialiste étant un *ingénieur* capable de concevoir et de dimensionner des machines, des systèmes, des installations, etc...

On remarque d'emblée que le champ d'activité d'un tel ingénieur est extrêmement vaste. La technologie jouera donc un rôle très variable suivant le domaine d'activité. En prenant par exemple le domaine des machines hydrauliques, l'ingénieur hydraulicien chargé de la conception de l'aubage doit connaître relativement bien la technologie de la machine. En effet, de très nombreuses contraintes liées à la conception mécanique de la machine vont sensiblement limiter les degrés de liberté du concepteur de l'aubage. Par exemple, le dessin du canal, la longueur, la forme générale, l'épaisseur, le mécanisme de commande des aubes, etc. sont fortement liés aux problèmes mécaniques.

En outre, il esttrès important que l'ingénieur hydraulicien soit capable de dialoguer, c'est-à-dire de bien se faire comprendre par ses collègues mécaniciens et électriciens, pour aboutir à une solution optimale à tous les points de vue.

Les mêmes considérations s'appliquent au domaine de la mécanique des fluides du génie civil. Là, également, les contraintes dues à la technologie sont très importantes et seul un ingénieur bien formé maîtrisera les problèmes et sera capable, le cas échéant, de collaborer étroitement avec des collègues de métier différent.

Actuellement, dans les centrales hydroélectriques par exemple, des défauts de coordination en phase d'étude et de conception provenant du cloisonnement des champs d'activité et du manque de formation et de dialogue entre les spécialistes hydraulicien, mécanicien, électricien et génie civil, occasionnent des difficultés, qui vont souvent jusqu'à des ennuis graves. La spécialisation est souvent extrêmement dangereuse dans les grands ouvrages faisant appel à des disciplines multiples.

Il existe par contre des cas où la technologie ne joue aucun rôle et où un ingénieur hydraulicien très « pointu » sera très à l'aise. On peut donner ici comme exemple la recherche fondamentale, le développement de logiciels, etc...

En outre, les grandes sociétés bien structurées peuvent très bien employer des ingénieurs très spécialisés, car de telles sociétés disposent d'ingénieurs généralistes possédant une longue expérience et étant capables d'assurer la coordination des projets.

Examinons maintenant la part réservée à la technologie, dans les études d'ingénieur, en France et en Suisse :

L'exemple de la France sera tiré de l'Ecole Nationale Supérieure d'Hydraulique et de Mécanique de Grenoble (ENSHMG), avec pour cas particulier la section d'Hydraulique. Les études se déroulent en 3 ans (6 semestres) :

La première année est entièrement consacrée aux bases mathématique et physique.

On trouve en plus 2 cours ayant un aspect technologique :

- Technologie des constructions mécaniques.
- Bureau d'études.

Le premier de ces cours donne les principes de la conception des organes de machines en fonction du procédé de fabrication, les techniques de liaison des divers éléments ou pièces, les problèmes de guidage (essentiellement les paliers).

Le cours *Bureau d'études* se divise en 2 parties qui sont la Conception et le dessin de génie civil et l'Analyse et la conception de mécanismes.

Le but de ce cours est essentiellement l'étude des dessins d'exécution et la maîtrise du langage graphique.

La part totale réservée à la technologie est relativement faible. Elle ne représente en effet qu'un total de 50 h.

La deuxième année est divisée par moitiés environ entre la fin du tronc commun et le début d'une spécialisation dans l'une des 3 filières suivantes :

- Mécanique des fluides industriels.
- Génie hydraulique et ouvrages.
- Ressources en eau et aménagement.

Le tronc commun de la deuxième année comprend la suite des branches fondamentale, mathématique et physique, ainsi que le début des cours de mécanique des fluides et des solides.

Dans le domaine de la technologie on trouve 2 cours qui sont :

- Conception de mécanismes.
- Oléohydraulique.

Le premier de ces cours propose par exemple la conception d'un tambour de treuil, d'une enceinte étanche à l'azote et l'organisation d'un poste de travail, avec une durée de 60 h.

Le deuxième, Oléohydraulique, d'une durée de 15 h, est divisé en 3 chapitres : problèmes de la transmission de puissance, représentation symbolique et étude des organes de conversion de l'énergie.

Les spécialisations de 2^{e} année proposent toutes les trois des cours de technologie.

La filière Mécanique des fluides industriels comprend les cours de technologie suivants :

- Métaux, matériaux, corrosion.
- Etude et conception de mécanismes.

Le premier cours, d'une durée de 15 h, donne les rudiments permettant de choisir un matériau, alors que le deuxième, d'une durée de 45 h, propose l'étude d'une pompe volumétrique, d'un récipient sous pression et du système de commande d'un générateur de houle.

La filière Génie hydraulique et Ouvrages propose 2 cours de technologie, intitulés :

- Béton armé.
- Constructions civiles.

Le cours de Béton armé, d'une durée de 30 h, donne les bases de la technologie du béton, alors que le cours de Constructions civiles est consacré aux techniques de base du génie civil avec une durée de 30 h.

La filière Ressources en eau et Aménagements reprend le cours de Constructions civiles.

La troisième année comporte relativement peu de cours de technologie. Les cours sont donnés sous forme de modules, d'une durée de 6 semaines, et ceci pour les 3 filières.

Il existe également un petit tronc commun comportant un cours de Régulation, servomécanismes et applications d'une durée de 21 h et un cours de Machines hydrauliques I d'une durée de 18 h.

La filière Mécanique des fluides industriels propose les cours de technologie suivants :

- Machines hydrauliques II 18 h.
- Machines à fluides compressibles 30 h.
- Etude et conception de mécanismes 27 h.

Ces cours sont des compléments aux cours donnés précédemment.

La filière Ressources en eau et Aménagements ne comprend pas de cours de technologie à proprement parler.

La filière Génie hydraulique et Ouvrages ne propose qu'un cours de calcul des barrages de divers types, d'une durée de 16 h.

En résumé, pour la filière Mécanique des fluides industriels, qui est la plus proche de la technologie, la part des cours de technologie est d'environ 260 h pour un total d'heures de cours de 1 080 h, soit 24 %.

Examinons maintenant le cas de l'Ecole Polytechnique Fédérale de Lausanne (EPFL), qui est assez proche de celui de l'EPF de Zürich :

Dans ces deux Ecoles, il n'existe pas de filière formant des ingénieurs hydrauliciens. En effet, les écoulements à surface libre ne sont traités que dans les sections de Génie civil, donnant le titre d'Ingénieur civil, alors que les écoulements en charge sont principalement abordés dans la section de Mécanique qui décerne le titre d'Ingénieur mécanicien.

Les deux formations sont donc beaucoup moins spécialisées en hydraulique proprement dite que la formation de l'ENSHMG à Grenoble.

La part de la technologie dans la section de Mécanique se compose des cours suivants dans le tronc commun des 3 premières années :

- Métaux et alliages 70 h.
- Machines et installations électriques 85 h.
- Formage des matériaux 30 h.
- Usinage des métaux 30 h.
- Eléments de construction 90 h.
- Conception des machines 90 h.

Ces cours ont des contenus assez semblables aux cours correspondants de Grenoble sauf pour le cours de Machines et installations électriques qui ne s'y trouve pas.

En **4e année,** les étudiants ont le choix entre 3 options, l'une d'elles étant l'Option Hydraulique. Dans cette option on trouve, en 4e année, les cours de technologie suivants :

- Turbomachines hydrauliques 110 h.
- Installations hydrauliques 20 h.
- Mesures hydrauliques 60 h.
- Turbomachines thermiques 90 h.

Le total des heures de technologie s'établit donc à 615 pour un total de 3 620 h, dont 2 155 h de cours. La proportion heures de technologie/heures de cours est donc de 28 % à l'EPF Lausanne.

On remarque que la formation des ingénieurs hydrauliciens est très différente dans les deux exemples considérés, Grenoble et Lausanne. La formation de base en mécanique des fluides et ses branches proches est bien plus importante à Grenoble, avec 306 h de cours (28 %) qu'à Lausanne, 190 h de cours (9 %), alors que la technologie est traitée plus en profondeur à Lausanne avec 615 h de cours (29 %) qu'à Grenoble, 260 h de cours (24 %).

Il faut toutefois remarquer que le nombre d'heures est plus faible. A Grenoble le nombre total d'heures est de 2 550 et le nombre d'heures de cours de 1 080.

Il est donc évident que la formation de l'ENSHMG est plus spécialisée que celle de l'EPFL. Un petit pays comme la Suisse ne peut pas former des spécialistes très « pointus », la demande étant relativement faible. Il en va, bien évidemment, différemment de la France.

Ce raisonnement qui est valable aujourd'hui le sera-t-il encore lorsque la construction de l'Europe sera complètement achevée et que la libre circulation des ingénieurs sera une pratique courante ?

Si cette libre circulation devient une réalité, on devrait assister à un profond changement du profil de l'ingénieur hydraulicien dont la formation pourra être adaptée à des besoins plus précis étant donné la très grande taille du marché de la future Europe.

G. Di Silvio, Professor of Hydraulics, University of Padua, Italy

Indicence of biology on the curriculum of the hydraulic engineer. Present conditions in Italy and possible developments

The situation in Italy will be briefly resumed. Particular emphasis will be given to the different types of specialists presently produced by the schools of engineering and by other related departments (biology, agriculture, forestry, chemistry, geology, architecture, etc.). An attempt will be made to answer the following questions. Who is a « hydraulic engineer » ? Is the hydraulic engineer expected to solve problems with high biology incidence, arising in hydraulic projects ? Is the hydraulic engineer prepared to solve these problems ? Is the hydraulic engineer capable to coordinate collaborators and consultants coming from the field of biology ? Is the hydraulic engineer capable to collaborate with and giving advice to supervisors coming from the field of biology ?

Possible developments of the present situation in Italy will be discussed.

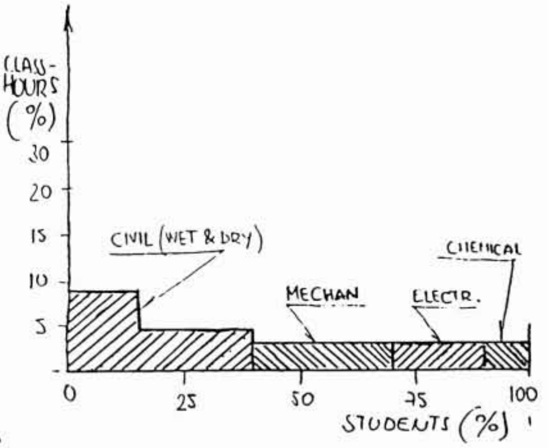
1. Who is a hydraulic engineer ?

Regardless the wide differences from country to country and from institution to institution, it has been typical of (inevitable to) our profession to expand progressively its specializations and to differentiate more and more their respective curricula.

In my country, for instance, the traditional training in hydraulics (or fluid mechanics) that 30 years ago was compulsory for all the (5-years course) engineers, is offered now to just a fraction of all the undergraduate students, although much more hydraulics is pumped into a very small number of them.

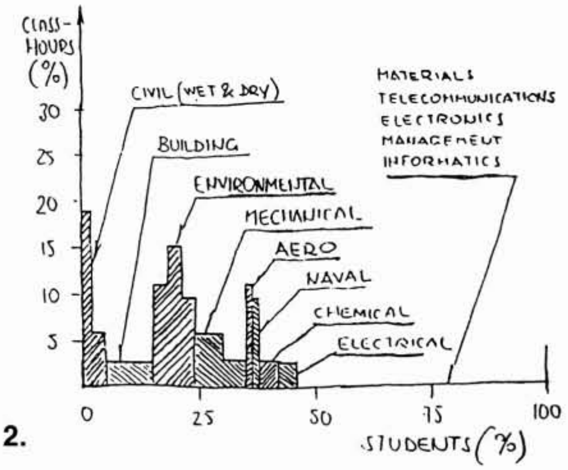
In other words, in the good old times when the traditional *four-leaf clover* repartition of engineering was still holding *(fig. 1)*, nobody was « born », but everyone could « become » a hydraulic

HOW MUCH HYDRAULICS FOR HOW MANY STUDENTS?



1.

Class-hours of Hydraulics and related subjects (% of total curriculum) versus number of students (% of total enrollment) in each department.



2.

Fig. 1. Reports the « four-leaf clover » repartition of engineering departments (up to the sixties);
Fig. 2. Reports the « marguerite » repartition (today).

engineer, with just a little personal effort after his graduation. With the present *marguerite* repartition *(fig. 2)* of engineering, by contrast, there is a little patrol of Civil engineers that have received an intensive training in hydraulics, hydrology and related disciplines, but the largest portion of graduates have no idea of how water flows (and apparently they live happily all the same) (*).

Yet, I would not comprise among the « hydraulic engineers » only those that have been labelled in this way by a Civil Engineering Department (in Italy, Corso di Laurea in Ingegneria Civile). First of all I would include among the hydraulic engineers all the specialists in hydraulic machinery and chemical installations (generally coming from Mechanical Engineering and Chemical Engineering Departments) who have had specific training in fluid mechanics. Secondly, hydraulic specialists may also be found in the new department of Environmental Engineering recently launched in several italian faculties (Corso di Laurea in Ingegneria dell'Ambiente e del Territorio), where the importance of biology is particularly relevant. Moreover, even curricula of other engineering departments with no courses of hydraulics or fluid mechanics often include subjects in which our problems are treated (I just mention some applications of system analysis to water resources management, of identification theory to rainfall time series, etc.). Last, one should recall that hydraulics and fluid mechanics are also taught in other departments outside the faculty of engineering (agriculture, forestry, geology, geophysics, architecture, etc.).

As hydraulics and biology often present several points of contact — no matter the faculty or department where the specific problem is treated — talking about the place of biology in the training of the hydraulic engineer, I will try to keep the definition of this professional the broadest as possible.

(*) For a more detailed information on the present Engineering curricula in Italy, see the lecture presented to this conference by C. Fasso'.

2. Contacts of hydraulics and biology

A large number of examples may be given where hydraulics and biology have points of contact. Following a problem-based classification, one may group these examples in the following fields: biomedical engineering, biotechnologies and environment.

Biomedical engineering, in its broadest sense, includes any contribution that our profession (engineering) can give to medicine and biology: from automatic processing of medical data (informatization of hospital files, expert systems and artificial intelligence in medicine...), to the design of prosthetic devices, to the mathematical modelling of physiological processes. The contribution of fluid mechanics, of course, can only be found in some prosthetic applications (e.g. heart valves...) and in biophysical modelling (emodynamics and, to a certain extent, dynamics of other biological fluids).

Biotechnologies, by contrast, take advantage of biological processes to achieve engineering goals. They include many aspects of chemical engineering (industrial fermentation and other biological techniques), civil engineering (biological revetments of structures and soil erosion control by vegetation) and sanitary engineering (sewage water treatments).

While biomedical engineering and biotechnologies generally represent the « friendly » face of the marriage between biology and engineering, *environment*, by contrast, is where the two partners often come to a clash. In fact, civil engineering works (especially large hydraulic projects) invariably have an impact on the environment. A careful assessment of the impact — and the design of measures for mitigating possible negative consequences — is nowadays a fundamental part of any project. On the other hand, amelioration and restauration of natural environment, sometimes damaged by less careful projects of the past, is increasingly demanded in industrialized countries.

In environmental problems the contact of hydraulics and biology (besides other disciplines, like geology, geomorphology, chemistry etc.) is apparent. In fact, not only most of the large civil engineering projects involve hydraulic structures, but water

Typical curriculum for the three branches of Environmental Engineering : A) Environmental Control, B) Soil Protection and C) Territory Management			
Number of didactic units in each group of disciplines			
GROUP OF DISCIPLINES	BRANCHES		
	(A)	(B)	(C)
Mathematics	4	4	4
Physics	2	2	2
General biology	1	1	1
General geology	2	2	2
Economics	1	1	2
Chemistry & Chem. engineering	5	3	3
Informatics & System analysis	3	2	2
Hydraulics & Hydr. engineering	3	4	3
Soil mechanics	1	3	1
Structures	1	2	1
Planning	1	1	3
Other engineering subjects	4	3	4
Total	28	28	28

(more than air or soil) is the « sphere » where most important biological processes take place.

3. Managing interdisciplinary relations. The client-supplier intercourse

Despite their specific differences, any type of interdisciplinary relation (e.g. between hydraulics and biology) may be seen as the intercourse between client and supplier. Indeed, we may consider as a « client » the person responsible for a project (project manager) in need of certain technical capacities, while the experts that possess these capacities represent the « suppliers ».

Normally the project manager is himself an expert, reasonably acquainted with the various aspects of the project. As long as his collaborators belong to the same trade, although with different specializations, there is no problem of communication, nor particular difficulties in the cooperation.

Problems arrive, however, if the project manager (the « client ») needs some know-how definitely outside his own profession. To fill this gap he first should go « shopping » on the market (find the right « supplier ») and then cooperate with him in carrying on the project. For doing that, client and supplier should either share a common language (from few basic words up to a total proficiency in each others tongue) or alternatively resort to an interpreter. The solution will depend on the quantity and quality of the information object of the transaction.

If we go back to the relation between hydraulics and biology, as depicted in the examples given before, the client-supplier intercourse will be different in each particular example.

In some examples the biological information required by the hydraulic engineer to solve his problem is either relatively simple (like in sewage treatment) or very specific (like in emodynamics) : in both cases there is no need for an extended training in biology as the information can be easily assimilated by any engineer with no prerequisites.

In other cases, conversely, is the amount of fluid mechanics information that is very limited. For example, in the design of vegetal protection (biological revetments) for civil engineering works, the botanical aspects are definitely dominant : what is needed of hydraulics (stresses by waves, currents or rain) can be supplied to the biologist who remains in fact the only expert in charge.

The problem is more difficult when a very complex system is concerned, like a global natural environment. In this situation biological and hydraulic processes (but also physical and chemical ones) are continuously interacting, in such a way that a much closer cooperation between project manager and each specialist (as well as among various specialists) is required.

In these circumstances, where a lack of deep understanding may even be fatal to the project, just a rudimentary knowledge of the others' language is not sufficient for a fruitful collaboration. This is the case in which the client-supplier intercourse can best be solved by means of an « interpreter ». The interpreter, reasonably proficient in many languages although not necessarily expert in every discipline, may or may not be in change as project coordinator ; in any case he acts the necessary liason-officer among specialists, with a professional role that is becoming more and more crucial for large and complex projects.

This professional role is going to be played in Italy by the *Environmental Engineer*, whose curriculum has been recently defined by the Ministry of University and Scientific and Technological Research. The Environmental engineer is in fact a wide-spectrum engineer, with a solid formation in mathematics, physics, chemistry and engineering sciences, but with some fundamental training in general geology and biology.

The 5-years curriculum in Environmental Engineering is composed by 28 didactic units (each unit of about 100 class hours), as any other type of engineering, and is slightly differentiated in three branches : A) Environment control, B) Soil protection and C) Territory Management. A typical curriculum for the three branches is given in the following table.

Conclusions

Relations between engineering and other sciences (particularly between hydraulics and biology) are rather numerous, with different characterizations. These relations, however, do not require as a rule a specific training in General biology by the engineer nor a specific training in Fluid mechanics by the biologist. Very often, indeed, either the information in the « alien » discipline that one needs to solve a problem is so limited that it can be properly taught in the « domestic » course where this information is utilized, or, conversely, the problem is so complex that only an expert can handle it.

By contrast, when biological and hydraulic processes are strictly linked, a continuous interchange is expected between biologist and engineer. In this case some *basic* knowledge of the other discipline is required ; this has been made in the curricula of Environmental Engineering and of Biomedical Engineering, where some fundamental biology courses (General Biology, Ecology and, respectively, Physiology) are offered to the engineering students.

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The water-related geophysical sciences

The role of the water-related geophysical sciences is reviewed in the light of formation of hydraulic engineers. First of all the curricula granting a first level degree are shortly discussed. The space for water disciplines is there quite narrow : no more than a general course on fluid dynamics, a second one on applied hydraulics, and third one on applied hydrology seem to be feasible to provide curricula granting a first level degree in civil or environmental engineering. Special curricula for a degree in hydraulic engineering (or water engineering) seem unsuitable at the first level because these should make culturally rigid the young graduate in comparison with the request for the professional work market.

The suitable space for water-related geophysical sciences has to be found inside curricula granting a second level degree. Understanding the main hydrologic processes — from moisture dynamics of atmospheric circulation to precipitation processes, as well as solid and liquid phase occurrence at the land surface, the soil, water and vegetation relationships, groundwater and related transport processes, drainage and fluvial morphology, till to near shore transport processes — has to form the bulk of the teaching experience together with the relevant mathematical and system analysis tools.

New technologies are now producing a large amount of new experimental evidence about hydrologic phenomena at space and time scales which defy the traditional engineering control, such as remote sensing, digital elevation models of the surface features, and geographycal information systems, must be mastered by the hydraulic engineer, or, in short, the water engineer of the year 2000.

1. Introduction

My contribution to the round table is obviously biased by my experience of the italian university ambient. I shortly summarize such an experience to give to the audience the opportunity to listen my speech with the minimum bias.

In Italy, at the beginning of the sixties, the school of engineering had been redesigned all over the country, framing out a five year curriculum in civil engineering. The first two years are mainly devoted to general physics, mathematics and chemistry ; the third year introduces the fundamentals, i.e. fluid mechanics and hydraulics, mechanics of solid bodies, applied thermodynamics, mechanical and electrical machinery : minor are the differences between the curricula offered to civil and mechanical engineers ; the forth year gives the applied fundamentals for a civil engineer, i.e. buildings and civil structures design, soil mechanics, hydraulic structures, water supply and sewerage systems. In the fifth year only the hydraulic connotation is introduced by fluvial hydraulics, hydrology, hydroelectic engineering, coastal engineering etc... The written thesis (or final work) is a project report in the field of hydraulics.

By this way the italian university graduates civil engineers-hydraulic section, and the section is mentioned on the diploma, with very uniform characteristics all over the country :

— a good ability for formal thinking, as a result of the first two years,
— a general good background on fundamentals,
— no ability, or a very reduced one for experimental and field work,
— no experience of professional work.

Recently the italian government — may 1990 — allowed the universities to reshape autonomously their curricula, and the diploma they offer. In the field of engineering two levels of study are thought : a first level, with three years, will produce the « ingegnere diplomato », something like the bachelor in engineering ; a second level, after two or two and half additional years will produce the « ingegnere laureato », something like the master in engineering.

The new water-related professional profiles in Italy in the next future will probably be two : the civil engineer, with a formation mainly oriented to the mechanics of the hydrologic cicle (in the sense of Klemes, 1986), and the environmental engineer with a formation mainly oriented to the thermodynamics of hydrological cicle.

The discussions I had with my colleagues in Genoa and the experience I got managing ERASMUS and COMETT actions at the European Community level greatly influenced my point of view in designing new curricula : new professionals will have to work in the integrated european system, where travelling from Milan or Genoa to London or Paris or Brussels is shorter than inside each country of origin.

2. The first level : is it possible to have a hydraulic engineer in three years ?

To design a first level curriculum it's an easy task if you don't take into account that students, to develop the ability of formal thinking and the capability of problem solving, they need not only materials but time.

On the other side the labour market requires, on the average, professional profiles with quite general and broad preparation, young enough to be employed at the first levels of the employee's career ; in addition they must be ready to move from a task to another without cultural resistance.

Such a person has to spend at university no more than four years, if he/she enters seventeen years old, may be less if older. Broadly speaking he/she will follow six-seven semesters (a semester of practical work, hopefully outside the institution, is highly recommended), made up of 250-350 classwork hours each.

The first level curriculum, most frequently, ends up with a degree in civil or environmental engineering. To get a more narrow spectrum degree, like a degree in hydraulic engineering or coastal engineering or water supply engineering etc... it seems quite unfeasible : it should require a trade off between fundamental preparation and applied training focused into disciplinary areas. With few exceptions based on local needs, a narrow spectrum first degree would produce low flexibility of the young graduates in meeting the labour market offers.

The previous analysis suggests that the space for hydraulic and water-related disciplines is quite narrow in the first level curricula ; sizing up such a space I should think at a total of about 300 hours of classwork including fundamentals of fluid mechanics, applied hydraulics and hydrology. For environmental engineers contents of physics of fluids and thermodynamics of the atmosphere will suitably take the place occupied by civil structures design in civil engineering curricula.

A few eligible courses, however no more than ten per cent of the total curriculum on the average, could enlarge the informations of the students in the fiweld of water and waste treatments, fluvial hydraulics, coastal engineering, but eventually no deep insight will be possible into the geophysical water-related sciences.

In summary it seems to me unfeasible to produce a first level professional profile strictly focused in the field of water ; the traditional general purpose profiles, civil and environmental engineers, can have only a penchant for hydrology, but mainly oriented to problem solving better than process understanding.

3. The second level of studies and the water-related geophysical sciences

Geophysical sciences of interest to the hydraulic engineer are mainly centered in hydrology. As Eagleson pointed out with the general lecture at Baltimore AGU meeting in the 89 spring, hydrology must be viewed as composed by a large spectrum of basic disciplines.

Large atmospheric phenomena and the dynamics of associated moisture are the processes to be understood to have a physical insight on quasi-periodical seasonal storm patterns on one side and on the space and time extent of dry periods on the other side : predictions and engineering design of water resources exploitation systems based only on stochastic hydrology tools are of little value if not combined with the capability to learn from the prognostic atmospheric variables worked out by the general circulation models (Eagleson, 1986).

The small mesoscale thermodynamics of precipitation processes, their space and time scales, with and without orographic enhancement, have a number of fields of interest in applied hydrology : from the regional analysis of extrem events to the use of remote sensing to perform warning procedures in hazardous areas (Rossi and Siccardi, 1989).

Snow and ice accumulation and melting and the runoff formation at the hillslope scale traditionally form the main bulk of hydrological modelling. However at the formation level of engineers traditional lumped models occupy more than seventy per cent of hydrologic books. The use of digital elevation models to capture topographic features and their role and the use of modern geographycal information systems to accomodate the space variability of the soil characteristics are till now not used in the teaching process.

Water movement in the unsaturated soils and the vegetation evapotraspiration processes, together with the related thermodynamics, will suitably have the correct central position in the water-related geophysical sciences. It is worth quoting Klemes (1986) statement « ... hydraulic engineer background, conditioned to dealing with water flowing over spillways, ... tend to see a river basin, and, indeed, the whole hydrologic cicle, as one big hydraulic machine where all the water is driven by the forces of gravity and friction... About 80 % of hydrologic activity in the basin, the evapotraspiration, which is driven largely by radiation energy, is treated in one or two per cent of a typical hydrology textbook and the remaining 98-99 % is devoted to the 20 % of the activity governed by gravity and friction... ».

A large chapter of traditional hydraulics, and hydrology is the occurrence and movement of groundwater ; in spite of the large advance in computationals tools water flow and solute transport processes in the unsaturated zone, the corresponding recharge of aquifers by water and contaminants, and the applications of stochastic subsurface hydrology have no space in the usual teaching for engineers ; by this reason dealing with multiphase non aqueous compounds, the main source of dramatic pollution of aquifers is now out of reach for the existing professional profiles.

Moving back to surface processes I would like to mention that only recently a connection between drainage and fluvial morphology, a typical theme from the schools of geography and geology, and the quantitative ability to deal with erosion, transport and deposition processes produced by the schools of engineering, is developing.

Global understanding of the drainage forms as a relic of past climatic events has to be introduced to give the suitable perspective to the man made fluvial waterworks and river training.

What I would to convey with the previous list of topics is the concept that a large part of the curricula of the second level in the field of water should be devoted to understanding main hydrologic processes. Hydrologic sciences are experiencing, in the present decade, an impending theoretical crisis (Dooge, 1986) ; from the past twenty years during which a period of « normal science » (Beven, 1987) developed a corpus of civil engineering tools we are now emerging into an innovation period : the availability of a large amount of new experimental evidence, till now quite unexploited at the scientific level, is opening the field for reshaping the educational issues.

In common with others geophysical sciences the water-related disciplines face a reality that demonstrates great complexity at small space scales, a complexity that ultimately defy the observation ability and the experimental control at the scale of engineering synthesis.

It seems to me necessary that, in the formation of the water engineer of the year 2000, we should attempt to move out from the mechanistic concept of our background : we should give geophysical sciences a chance to become a primary field to interest in university curricula, increasing the emphasis on process understanding while rising problem solving ability and professional standards in practicing.

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Training of hydraulic engineers. Particular problems in relation to developing countries

The need for well trained hydraulic engineers is very high in developing countries because of the number, the size and the variety of the problems which have to be solved. Whilst, in the developed countries most of the major hydraulic problems have been solved in many third world countries the problems and the needs are just now being identified and solutions have to be proposed in irrigation and drainage, flood control, sedimentation and erosion problems, river transportation, coastal engineering and harbours, urban drainage and waste water treatment, drinking water production and distribution.

It is logical and understandable that those countries want to become independent from foreign consultants or at least be able to evaluate the proposals made by international firms and, in short, to be valuable counterparts.

The education in engineering in general and in hydraulics in particulars however is in most countries of a relative low level. Engineers are instructed to use simple methods and rules of thumb without understanding thoroughly the underlaying concepts. The easy availability of PC's and software af all kind, origin and quality only accentuates the need for a good understanding of the basics of hydraulics to carefully interprete and relativate results obtained from a « black box ».

The problem actually is either a lack of understanding and a lack of modern technology to solve the problems faced, or the abundant availability of powerfull tools which are not mastered and used without care. Although engineers of developing countries must get acquainted with computermodels and data collection and processing methods, the major accent when upgrading those engineers should be on a thorough and rigourous analysis of the physical mechanisms.

When tranfering technology to developing countries we continuously must bear in mind that it should be *appropriate* technology. The environmental conditions, the scale of the projects, the available budget and manpower may be quite different from what we are used at in Europe. The same holds true for the (MSc or PhD) research that we organize for students from third world countries. It is of no help to get them acquainted with supercomputers or sophisticated laser measurement equipment if they can not validate this work is their own country.

Europe has a very important duty to spread hydraulic engineering knowledge towards developing countries, but our efforts should be specific and adapted both to the antecedents of the students and their future working conditions.

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Problèmes spécifiques aux pays en voie de développement

Préambule

Intérêt d'un corps de spécialistes autochtones pour des questions hydrauliques — génie civil dont le faciès « local » est très important : Hydrologie (crues, étiages, leur mesure). Ressources en eau disponibles. Le terrain (Géologie, Mécanique des sols).

Son importance dans le relevé et le stockage des données.

Les inconvénients d'une solution de remplacement par des organismes qualifiés étrangers.

A) Différence de philosophie de la formation en fonction du degré d'évolution du pays considéré

— Cas des Pays Industrialisés (PI)

- Fabrications de haut niveau.
  Airbus, Ariane, Equipement, Hydromécanique
  Barrages de forme sophistiquée (Roselend, permettant de remplacer de la main-d'œuvre non qualifiée par du personnel de plus haut niveau).
- Présence de techniciens très qualifiés, permettant de réserver les interventions de l'Ingénieur à des niveaux de compétence plus élevée.
  Remarque : Tendance à l'abus de cette position en France.
  Tendance à la dégradation.
- Surtout : Existence d'un « Tissu » Industriel très dense, d'équipes compétentes dans des domaines très variés, constituant indirectement des « pôles » de formation diffus mais très puissants, notamment pour les jeunes cadres sortant des Ecoles.

— Cas des pays « En développement » (PVD).

- Situation pratiquement opposée sur ces trois points.

B) Philosophie de la formation et niveau de développement d'un pays. Les difficultés de la coopération en matière de formation

— Le système de formation en général est défini par les traditions d'un pays et ses réalités socio-industrielles. Les PI ont besoin d'une formation à fort contenu scientifique nécessaire pour le premier point cité ci-dessus et rendu possible par les deux autres.

— Le « transfert » du système d'un pays à un autre, par le biais de la coopération, pose donc des problèmes, largement méconnus et sous-estimés. Exemple : les diverses façons de présenter la méthode des éléments finis en France ou en Algérie (Exemple vécu).

Les PVD doivent largement développer les enseignements technologiques et appliqués au niveau de l'Ingénieur : l'absence d'un corps de techniciens compétents les oblige à s'en occuper, et ils ne disposent pas de structures industrielles permettant de compléter la formation dans le domaine technologique au cours de la vie professionnelle elle-même. Ils doivent être opérationnels dès la sortie du système scolaire, car ils ne trouveront personne pour les aider dans la pratique du métier.

Un autre point surgit : l'importance des « technologies douces », à préférer en PVD pour utiliser des procédés plus en rapport avec la « Pyramide des compétences » de leur main-d'œuvre. Exemples : Alternative Béton armé normal ou Béton précontraint (et préfabriqué) ; le barrage du Djen-Djen (Algérie, 1962). Alternative irrigation traditionnelle, par aspersion, ou goutte-à-goutte.

L'influence du prestige des « Technologies dures », mais leur désadéquation de la situation socio-économique des PVD.

Le heurt des systèmes de formation peut favoriser le « Brain drain ». Formés à un niveau élevé, certains étudiants ne retournent qu'avec appréhension dans des structures où ils n'auront pas beaucoup l'occasion de mettre en œuvre ces connaissances.

— La formation aux disciplines de base est sans doute plus facile — sous un certain aspect — que la formation à la technologie.

La première précise le « Pourquoi » par un savoir « structuré » (notamment par les mathématiques, qui permettent ensuite de « lire »), presque sans faciès local. La seconde précise le « Comment », la structuration en est beaucoup plus difficile. Les paramètres sont toujours très nombreux et parfois difficiles à dénombrer (surtout si on tient compte des questions de coût, des influences locales dans les choix techniques).

C) Le très grave risque d'accroissement du « Gap », du fait des progrès foudroyant des « techniques dures », ou des méthodes d'étude en général. La nécessité d'une solution pour le développement de la coopération

— Trois formes de coopérations possibles :

Création d'Institutions locales de formation. Ces Institutions peuvent avoir une structure Nationale (Cas de l'ENIB — Ecole d'Ingénieurs de Bamako), ou Inter-Etats : Cas de l'EIER — Ecole inter-états des Ingénieurs de l'Equipement Rural, à Ouagadougou (pour l'Afrique francophone), CIDIAT — Centro Interamericano de Desarollo Integral de Aguas y Tierras (Centre Interaméricain de Développement Intégral des Eaux et des Terres), à Merida, au Venezuela, l'AIT — Asian Institut of Technology — à Bangkok.

Participation de Professeurs des PI, au fonctionnement des Institutions de formation propres locales sous les quelques réserves suivantes :

Les enseignants investis de ces fonctions doivent les assurer avec une certaine stabilité, de façon à bien connaître les choses et les gens avec lesquels ils sont amenés à travailler. Il est essentiel que les pays faisant appel à ce type de coopération assurent ce que la FAO appelle la « Contre partie », c'est-à-dire un corps enseignant local « jumelé » avec les Etrangers, pour insister sur le faciès particulier des problèmes, se former eux-mêmes pour un jour remplacer les étrangers (L'éducation est l'art de se rendre inutile...).

Accueil des étudiants des PVD dans les PI, suivant les conditions « normales » ou dans des conditions particulières, définies parfois dans des accords spéciaux, d'un établissement à un autre.

— De toute façon, cette collaboration ne sera fructueuse que si un certain nombre de conditions sont respectées.

Le personnel doit absolument avoir été sensibilisé — voir formé (par exemple lors de séminaires spécialisés) — à la nécessité de changer ou de renouveler dans les pays où il va enseigner les méthodes appliquées dans son propre pays, parfois profondément. Il ne doit en aucun cas se borner à reprendre le schéma des enseignements donné dans son pays, la même pédagogie, les mêmes types d'application.

Pour ces diverses raisons notamment, une coopération efficace coûtera certainement cher. Elles impliquent un vigoureux effort d'adaptation, qui pourra limiter encore le nombre des candidats, en tout état de cause pas considérable. Par contre la création d'équipes avec un minimum de compétence dans les PVD peut apporter des bénéfices plus importants que le soupoudrage par une aide parfois difficile à orienter.

D) La disparité des situations des « Pays en développement » pris dans leur ensemble

Parallèlement, les situations PVD sont extrêmement variées et recouvrent des situations très disparates, qui impliquent des solutions très différentes, alors qu'il s'agit apparemment d'un seul et même problème de formation.

— A une extrémité se trouvent des pays tels que l'Argentine, le Brésil, le Chili, le Mexique, le Venezuela, l'Indonésie, les Indes.

Ils sont demandeurs de formation à un niveau assez élevé, concernant surtout le transfert vers les applications des derniers progrès scientifiques. Par contre, le développement des aspects axiomatiques ou purement théoriques ne les intéresse que rarement (Cas vécus). Ils ont assez souvent des idées précises sur ce qu'ils souhaitent. Des conflits peuvent surgir avec le pays d'accueil, qui lui entend respecter ce qu'il appelle le « niveau » des thèses, Français ou Etrangers confondus.

— A l'autre extrémité se trouvent les « nombreux pays les plus pauvres du monde » : beaucoup de pays Africains (Mali, Burkina, Faso..., la Bolivie, Haïti, le Laos...

La situation est telle que seule une vigoureuse intervention (Est-elle souhaitée ?) risquerait de faire progresser les problèmes, dans des conditions qui nécessiteraient une difficile étude préliminaire, à conduire peut-être au niveau International (UNESCO).

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Training of the hydraulics engineer in Italy today

1. Introduction

A brief introductory account of the characteristics of the University system in Italy seems necessary to focus the cultural and institutional frame in which the training of hydraulics engineers is presently carried out in this country.

Until the beginning of last year the whole system of state schools in Italy, including the Universities, was regulated by the Ministry of Education. On May 9, 1989 the law no. 168 established the new Ministry for the University and Scientific and Technological Research (MURST), which took over the responsibility of the Universities.

Following this institutional change, the process of evolution and modernization of the University system, already in progress for a least thirty years, became deeper and faster. For this reason the Italian University system is presently undergoing a profound renovation process, which is likely to change substantially some of its main characteristics in the next few years, and which is still in full progress.

To show the importance of the problems still on the table, and the impact that their possible solutions may have on the next generations of graduates from all University Faculties, including hydraulic engineers, suffice it to quote some laws which have been proposed by the MURST and are being discussed by Parliament. These laws, aimed to modernize and improve the University functioning through the introduction of some profound innovations, take into consideration such fundamental items as : autonomy of the Universities ; teaching regulation, including the introduction of an undergraduate degree ; right to study. The first of these laws, devoted to the autonomy of the Universities, has been approved and has been operative for a few months ; but, since the others are still under discussion, one cannot anticipate which answers will be given to some fundamental questions as e.g. the introduction of new levels of degrees.

In such a situation it is clear that the description of the Italian University system which can be made today must be viewed as just a temporary picture and is likely to have to be updated rather soon. A warning which holds to some extent also in the particular area of hydraulic engineering.

2. On the italian University system

Until the beginning of the 80's only one level of degrees was conferred by the Italian University Faculties, called the « Doctor » degree. In particular the graduates from Engineering Faculties received the degree of « Doctor in Engineering ». This degree has a legal value, inasmuch as it is an indispensable requisite for the admission to the state Examination which must be passed to get official authorization to the professional activity of Engineer in this country.

With the law no. 28 of 1980 and the subsequent Decree of the President of the Republic (D.P.R.) no. 382 of July 11, 1980 a postgraduate degree called « Doctor of Research » was introduced. This degree is somewhat similar to the doctoral degrees (Ph.D.) in other countries, but has some peculiar features which will be described in Art. 3. Its introduction represents an important step towards the modernization of the Italian University system, it has no legal value (in the sense explained for the simple « Doctor » degree) and has been conceived essentially as a privileged channel for the formation of researchers to be employed in the Universities and in public and private research institutions.

As will be seen in the following, the number of postgraduate students is kept very low. Due to this fact and tot the particular area of employment of the Doctors of Research, it appears that the professional qualification of Italian engineers is practically based upon only one level of University degree.

As a matter of fact, Italy is one of the very few countries in the world where Universities do not confer undergraduate degrees. Although repeated proposals for the introduction of a first level degree have been advanced over the years, and although there is a large and increasing potential demand for this kind of intermediate qualification from the industrial and economic world, we are still awaiting the changes in legislation required to introduce such essential improvement in our University system. Since MURST is actively working in this direction, as we have seen in Art. 1, it is likely that the solution of this basic problem will be reached quite soon.

Postgraduate specialty courses (« Corsi di perfezionamento » and « Corsi di specializzazione »), leading to a certificate or a diploma, may be taught in the University Faculties. In general they are attended by relatively few, with the exception of those organized by the Faculties of Medicine. In the Engineering Faculties the quantitative importance of the attendance at specialty courses can be considered marginal, especially in the field of hydraulic engineering.

Over the last decades courses for continuing education and training of practitioners have become more and more popular in many branches of the engineering profession, including hydraulic engineering. They are taught chiefly in the Universities, often in collaboration with professional associations (e.g. in the field of sanitary engineering, which is strictly connected with hydraulic engineering, a noteworthy activity of this kind is carried out by the National Association for Sanitary and Environmental Engineering (ANDIS)). Some courses for continuing education and training are directly organized by research institues and public agencies.

3. Teaching of engineering in Italy (*)

3.1. Some quantitative data

Engineering is taught in Italy by 28 Engineering Faculties, all encompassed in State Universities. Of these Universities two are

(*) Some of the disciplines taught in Italian Universities have cultural and scientific contents somewhat different from those taught under similar names in UK or in the USA, due to the different traditions and cultural background of the respective countries. Therefore the word by word translation into English of the Italian names of curricula, syllabuses and courses may be sometimes inadequate or even mistaken. In such cases I will drop the literal translation and adopt English denominations better corresponding to the actual contents of the disciplines, adding to the first quotation the original Italian denomination in brackets.

technical schools, each including only the Faculty of Engineering and that of Architecture : they are the « Politecnici » of Milan and Turin. In all the remaining Universities a variety of other Faculties is present besides that of Engineering.

According to the data published by the Central Institute of Statistics (ISTAT), in the academic year 1988/89 the total number of students attending the five years of the regular curricula was 83811 and that of teachers (Full Professors plus Associate Professors) was 3685 : therefore the 28 Faculties had on average 22.74 students per teacher. The total number of Research Assistants was 1112, with an average load of 75.37 students per assistant. The actual figures may differ materially from these averages not only from one University to another, but within the same University from one curriculum to another and in the different years of the quinquennium (only the first two of which are generally overcrowded). In particular the specific courses in Hydraulic Engineering are part of the curriculum in Civil Engineering, which is not amongst the most well attended, and are taught in the last two years of the quinquennium : therefore for two reasons they have reasonably low student-to-teacher ratios, of the order of ten.

The Faculties are quite different in size, as can be seen from the number S of students attending courses in the said academic year (ISTAT data) : fifteen Faculties had $S < 2\,000$; ten (including the Politecnico of Turin) had $2\,000 < S < 8\,000$; two (Napoli and Roma « La Sapienza » (**)) had $8\,000 < S < 12\,000$; the Politecnico of Milan was the largest, with $S = 15\,427$ (and with the highest — viz. the less favourable — student-to-teacher ratio : 39.66).

All the curricula for the Doctor in Engineering degree have an official duration of five years, enforced by law. However the majority of the students take longer : according to statistics developed in a report of March, 1990 by a Commission appointed by MURST, less than 10 % of the freshmen manages to graduate in 5 years and the actual average duration of Engineering studies throughout the country is presently 7.12 years. The order of magnitude of such figures is valid also in the particular area of hydraulic engineering.

With the exception of the Universities of Basilicata, Calabria, Parma and Trento, the number of students in the Engineering Faculties is not subject to any limitation and consequently there is no selection of the students applying for enrollment as freshmen. One of the consequences is that a large number of students drop out of University after one or two years, when they realize that the engineering studies are too difficult or ill-suited to their abilities and aptitudes.

In fact the dropout rate, viz. the percentage of students failing to graduate, is presently very high in the Italian Engineering Faculties : around 70 % of the enrolled freshmen. Since this phenomenon represents a heavy cost for the country from the social, economic and human points of view, it is the object of much concern and discussion within the academic community. The impending introduction of the undergraduate degree — although chiefly requested for other reasons, as we have seen — will most likely contribute also to the solution of the dropout problem.

A total of 6 000 engineers graduated in 1987, corresponding (the total population of the Republic being 57.2 million) to 0.105 graduates per 1 000 inhabitants. Comparison of this figure with those of other European countries shows that the number of engineers trained in Italy is inadequate : suffice it to say that in Germany (FRG), UK and France in the same year (1987) the graduates in engineering were respectively 0.510, 0.258 and 0.264 per 1 000 inhabitants. One of the reasons for this discrepancy is that the other countries have two levels of engineering degrees (the Doctoral degree apart) and engineers of both levels were included in the figures quoted, while in Italy an undergraduate degree does not yet exist. These remarks, valid in general for the whole field of engineering, apply in particular to the training of hydraulics engineers.

(**) There are two State Universities in Rome, the oldest called « La Sapienza » and the youngest « Tor Vergata ». Both have an Engineering Faculty.

3.2. *The institutional framework*

3.2.1. The degree of « Doctor in Engineering »

In Italian Universities the freedom of teaching has always been guaranteed (with some exceptions during the fascist period) as to the contents of the disciplines taught. As for the curricula the autonomy of each University has always been rather restricted, so that the curricula are quite similar in different Universities. This follows apparently from the fact that the degree of « Doctor in Engineering » awarded by the Universities has a legal value, with the consequence that the government must guarantee a sufficiently uniform standard of training.

According to the law no. 910 of December 11, 1969, a University student can follow either one of the official curricula operative in the Faculty he or she wants to attend, or a personal curriculum. In the latter case he or she has to submit the proposed curriculum to the Faculty, which will approve it only after judging it congruous with the cultural and professional purposes of the desired degree and compatible with the existing legal contraints (and obviously composed of disciplines actually taught in the University to which the Faculty belongs). However in the Engineering Faculties — contrary to the humanistic ones — the students taking advantage of this opportunity are few and propose only changes of minor importance with respect to the official curricula. Therefore in the present report only the official curricula will be discussed, since they represent quite well the average training of hydraulic engineers in Italy.

The curricula of the Engineering Faculties have to conform to the directives of the Decree of the President of the Republic (D.P.R.) of May 20, 1989 entitled « Modifications of the University teaching regulation with regard to the curricula of the Engineering Faculty ». An account of at least the most important of such directives seems necessary in the present report, since it is likely that they will regulate the teaching of engineering in Italy for several years to come.

All the curricula of the Engineering Faculties must have the duration of five years, as already stated in the preceding Articles.

Fourteen curricula (« Corsi di Laurea ») may be activated in the Engineering Faculties, namely :

two in the area (« Settore ») of Civil Engineering : Civil Engineering and Building Engineering ;

three in the area of Information : Telecommunication Engineering, Electronic Engineering and Engineering of Computer Science ;

seven in the area of Industrial Engineering : Aeronautical Engineering, Chemical Engineering, Materials Engineering, Electrical Engineering, Mechanical Engineering, Naval Engineering, and Nuclear Engineering ;

two belonging to more than one area : Operational Engineering and Environmental and Territorial Engineering.

Each curriculum may encompass different syllabuses (« Indirizzi ») also listed in the abovementioned D.P.R. In particular Hydraulic Engineering is included as a syllabus in the Civil Engineering curriculum. The other possible syllabuses in such curriculum are : Building (obviously only in those Faculties where the

Building Engineering curriculum is not operative), Geotechnics, Structural Engineering and Transportation.

Every four years the official list of the curricula and syllabuses can be modified on the basis of teaching experience and/or the demand for new professional qualifications.

Only a part of the curricula is activated in each Engineering Faculty : in the academic year 1988/89 the curricula opeartive in the 28 Faculties were altogether 125, say on average 4.5 per Faculty (the richest Faculty as tot the number of curricula was that of the Politecnico of Milano, with 9).

Each curriculum or syllabus must include 27 to 29 one-year courses, the actual number being specified by the Faculty bylaws. A one-year course, officially named in Italian « annualita », is defined as a course covering 80/120 hours of didactic activities. Some of the one-year courses can be substituted by two half-year courses (« semi-annualita »), viz. by two courses covering 40/60 hours each.

The definitions of one-year and half-year courses are based upon the number of teaching hours, irrespective of the fact that they are distributed throughout the whole academic year or concentrated in a semester. In fact, the matter of the actual duration of the courses — whether annual or semestral — is left to the Faculty autonomy. Presently the large majority of Engineering Faculties in the country are organized on the basis of annual courses, although some of the major Faculties have been operated satisfactorily on semestral schedules for several years, as e.g. those of the University of Padua and of the Politecnico of Turin. In some of the other Faculties the advantages of the semestral courses are being felt and semestral schedules are likely to be introduced in the next few years ; in particular the Engineering Faculty of the Politecnico of Milan has decided to change gradually to the semestral schedule, starting from the academic year 1990-91.

In most of the Engineering Faculties the student, once he or she has passed the examinations of all the courses of the curriculum, is required to prepare a thesis and to discuss it with a commission of teachers.

The courses constituting each curriculum or syllabus are determined by the Faculty, which must select them (with the rules which will be explained in the following) from among those listed in a table attached to the D.P.R. of May 20, 1989. This table is the result of a worth-while effort towards the rationalization of the existing teaching regulations done by some Committees of teachere and by the elective advisory board of the MURST, the « Consiglio Universitario Nazionale » (CUN) : the result of this effort has been the reduction to 1.027 of the more than 2.500 disciplines included in the bylaws of the 28 Faculties at the time the Decree was issued, a number which has been artificially enlarged in the past by the introduction of very similar disciplines under different names in different Universities, owing to local traditions and cultural backgrounds.

In the D.P.R. the disciplines are classified into 106 groups (« raggruppamenti disciplinari »), according to the affinity of their contents. For instance the three groups regarding the specific disciplines of hydraulic engineering are named after « Hydraulics », « Hydraulic and Marine Engineering » and « Sanitary and Environmental Engineering », and include respectively 11, 19 and 11 courses (see next Art. 4).

The selection of the courses is made by the Faculty in two steps, in both of which a reasonable degree of autonomy is guaranteed, subject to the general constraints of the D.P.R.

In the first step the bylaws (« Statuto ») of the Faculty are issued, a document listing the curricula and syllabuses which the Faculty proposes to activate and the groups of disciplines of the D.P.R. from which the respective courses will be taken. The Faculty can modify the bylaws every four years, with the approval by MURST (which asks the CUN for counsel on this subject).

As a second step a manifesto (« Manifesto annuale degli studi ») is issued at the beginning of each academic year. In this document the Faculty announces which of the curricula and syllabuses listed in the bylaws will actually be activated and which of the courses included in the groups listed in the bylaws will actually be taught in each curriculum and syllabus. In this step the Faculty can also divide a syllabus into sections oriented towards different professional branches. Since the manifesto can be modified every year, it is possible for the Faculty to make some adjustments in the teaching schedule, within the framework of the bylaws, even during the quadrennium of validity of the latter.

The groups of disciplines listed in the bylaws for any syllabus must conform to the following rules, dictated by the D.P.R. :

nine groups of disciplines must be common to all the curricula of the Faculty ;

at least six groups must be common to the curricula of the same area ;

at least five groups must be characteristic of the curriculum ;

at least three groups must be characteristic of the syllabus.

The Faculty is free to choose the remaining courses, for which the D.P.R. does not contain specific rules. Some of these courses can be enforced by the Faculty and some (ordinarily four or five) can be left to the student's choice ; however the student is required to select such courses from among those proposed by the Faculty in the annual manifesto.

The nine courses common to all the curricula include the basic disciplines of mathematics, physics and chemistry as well as one course in engineering economics, with minor variations from one Faculty to another. As for the courses of the other categories more significant differences may exist, since the lists in the D.P.R. are somewhat abundant.

3.2.2. The degree of « Doctor of Research »

The doctoral degree is conferred after a three-year program, which cannot be attented in one University alone. In fact a « consortium » of two or more Universities is to be established for each subject for which a doctoral degree is offered.

The candidate must pass an entrance examination. During the 3-year term he or she must attend seminars and advanced courses taught by professors of the Universities belonging to the consortium and by other experts, and prepare a research thesis ; part of the time may be spent attending courses and doing research work in foreign Universities.

The number of participants for each consortium and for each 3-year term is limited to a figure fixed by MURST. A government scholarship is granted to each graduate student for the three years ; a law of the end of 1989 introduced an additional 2-year scholarship enabling research activity after the attainment of the « Doctor of Research » degree. A certain number of foreign students can be admitted to each term, but with no right to government grants.

4. Teaching of hydraulic engineering

4.2.1. The degree of « Doctor in Engineering »

According to the Decree of the President of the Republic of May 20, 1989, the three groups of disciplines regarding the specific topics of hydraulic engineering consist of the following disciplines :

Group « HYDRAULICS » : Dynamics of turbulence ; Hydraulics ; Environmental hydraulics ; Hydraulics of porous media ; Fluvial hydraulics ; Numerical methods in hydraulics ; Hydrodynamics ; Hydroelasticity ; Fluid mechanics ; Hydraulic measurements and controls ; Hydraulic modelling.

Group « HYDRAULIC AND MARINE ENGINEERING » : Urban hydraulics (« Acquedotti e fognature ») ; Irrigation and drainage ; Drainage and run-off regulation (« Bonifiche e sistemazioni idrauliche ») ; Hydraulic Engineering (« Costruzioni idrauliche ») ; Off-shore structures (« Costruzioni in mare aperto ») ; Marine engineering (« Costruzioni marittime ») ; Hydraulic systems operation (« Gestione dei sistemi idraulici ») ; Water resources management (« Gestione delle risorse idriche ») ; Marine and coastal hydraulics (« Idraulica marittima e costiera ») ; Ground water hydrology ; Hydrology (« Idrologia tecnica ») ; Waterways ; Special hydrotechnical installations ; Basic hydrotechnical installations (« Infrastructture idrauliche ») ; Harbour engineering ; Land reclamation (« Protezione Idraulica del territorio ») ; Coastal dynamics and protection (« Regime e protezione dei litorali ») ; Regulation of river basins (« Sistemazione dei bacini idrografici ») ; Techniques of hydraulic works.

Group « SANITARY AND ENVIRONMENTAL ENGINEERING » : Dynamics of pollution (« Dinamica degli inquinanti ») ; Pollution phenomena and environmental quality control ; Operation and control of plants for sanitary and environmental protection (« Gestione degli impianti di ingegneria sanitaria-ambientale ») ; EIA of works for sanitary and environmental protection (« Impatto delle opere di ingegneria sanitaria-ambientale ») ; Plants for treatment of gaseous effluents ; Plants for treatment of solid wastes ; Treatment plants for municipal and industrial water supply (« Impianti di trattamento delle acque di approvvigionamento ») ; Plants for treatment of waste waters ; Treatment plants in sanitary and environmental engineering (« Impianti di trattamento sanitario-ambientali ») ; Sanitary and environmental Engineering (« Ingegneria sanitaria-ambientale ») ; Techniques of works for sanitary and environmental protection (« Tecniche costruttive delle opere di ingegneria sanitaria-ambientale »).

The curriculum in Civil Engineering is operative in 23 Universities, and in 16 of these the syllabus in Hydraulic Engineering is taught. The latter are the two Politecnici of Milan and Turin and the Universities of Bari, Bologna, Cagliari, Catania, Firenze, Genova, Napoli, Padova, Palermo, Parma, Pavia, Pisa, Roma « La Sapienza » and Trieste.

As a paradigm of the present study plans for hydraulic engineering in Italy, that proposed in the manifesto of the Politecnico of Milan for the coming academic year 1990/91 warrants further comment. Here the syllabus in hydraulic engineering embraces two sections, oriented respectively towards Hydrotechnical installations (« Orientamento impianti idraulici ») and Sanitary Engineering (« Orientamento Sanitario »).

In such study plan the 11 courses of the first two years and 3 of the 6 courses of the third year are common to the other syllabuses of the curriculum in Civil Engineering, viz. :

1st year : Geometry ; Chemistry ; Mathematical Analysis 1 ; Physics 1 ; Civil engineering draft (« Disegno civile ») ;

2nd year : Mathematical Analysis 2 ; Fundamentals of computer science ; Materials engineering and applied chemistry (« Tecnologia dei materiali e chimica applicata ») ; Theoretical mechanics (« Meccanica razionale ») ; Physics 2 ; Engineering economics (« Economia applicata all'ingegneria »), which the student may substitute optionally with Valuation (« Estimo ») ;

3rd year : Structural mechanics (« Scienza delle costruzioni ») ; Hydraulics ; Electrotechnics, covering a half-year course.

After these courses common to all the syllabuses of Civil Engineering, the 3rd year of the sullabus in hydraulic engineering schedules the following courses :

Mechanics of machines (« Meccanica applicata alle macchine »), covering a half-year course ; Applied geology ; Applied thermodynamics (« Fisica tecnica ») ; Sanitary and environmental engineering 1.

In the last two years the two sections (« Orientamenti ») of the syllabus differentiate in most courses. For some courses of these years the manifesto indicates optional disciplines and the student can choose among them.

4th year for both sections : Structural Design 1 (« Tecnica delle costruzioni ») ; Hydrology ; Hydraulics 2, Architecture (« Architettura tecnica ») ; one optional course between : Surveying, Statistical methods (« Trattamento delle ossevazioni »).

4th year for the section oriented towards Hydrotechnical Installations : one optional course between : Treatment plants for municipal and industrial water supply, Plants for treatment of waste waters.

4th year for the section oriented towards Sanitary Engineering : Treatment plants for municipal and industrial water supply.

5th year for both sections : Hydraulic engineering ; Fundamentals of geotechnics ; one optional course among : Laud-use engineering (« Ingegneria del territorio »), Urban planning, Systems analysis, Modelling and management of natural resources (« Modellistica e gestione delle risorse naturali »).

5th year for the section oriented towards Hydrotechnical Installations : Special hydrotechnical installations ; one optional course among : Regulation of river basins, Coastal dynamics and protection, Hydraulic Engineering 2, Marine engineering ; another optional course among : Treatment plants for municipal and industrial water supply, Plants for treatment of waste waters and a list of 10 disciplines common to both sections.

5th year for the section oriented towards Sanitary Engineering : Plants for treatment of waste waters ; one optional course among : Plants for treatment of gaseous effluents ; Sanitary and environmental engineering 2 ; Applied ecology (« Ecologia applicata all' ingegneria ») ; another optional course among : Special hydrotechnical installations ; Coastal dynamics and protection, Regulation of river basins, Hydraulic Engineering 2, Marine engineering and a list of 10 disciplines common to both sections.

The 10 optional disciplines of the 5th year common to both sections (some of which were also suggested as optional disciplines for the preceding years) are not specific to hydraulic engineering, but belong to other fields of Civil Engineering, so that their choice can contribute to broaden the professional culture of the graduate. They are : Legislation (« Disciplina giuridica delle attivita' tecnico-ingegneristiche ») ; Corrosion engineering (« Corrosione e protezione dei materiali ») ; Applied geophysics ; Statistical methods ; Structural design 2 (« Progetto di strutture ») ; Steel design (« Costruzioni in acciaio ») ; Bridges (« Costruzione di ponti ») ; Valuation ; Remote sensing ; Numerical analysis.

The syllabus includes 28 one-year courses and 2 half-year courses. The optional courses left to the student's choice are 6 in the section oriented towards Hydrotechnical Installations and 5 in that oriented towards Sanitary Engineering.

4.2.2. The degree of « Doctor of Research »

In the field of Hydraulic Engineering three « consortia » have so far been established. The doctoral degree conferred and the Universities grouped into each of them are :

— Doctor of research in Hydraulic Engineering : Politecnico of Milan, Politecnico of Turin and Universities of Bologna and Pavia ;

— Doctor of research in Hydrodynamics : Universities of Genoa, Padova and Florence ;
— Doctor of research in Sanitary Engineering : Universities of Naples, Palermo and Rome « La Sapienza ».

As wa have seen in Art. 3.2.2, the number of postgraduate students for each consortium and for each 3-year term is limited to a figure fixed by MURST. In the terms so far operated (the fifth term started in 1990) the authorized numbers for the above-mentioned consortia were of four to nine, not including some foreign students.

5. Concluding remarks

From the methodological point of view, the training of hydraulic engineers in Italy is made according th what may be called a descending approach, viz. starting with the general and proceeding to the special. The same is true for the other branches of engineering.

Hydraulic engineering as one of the branches of Civil Engineering has an old and distinguished tradition in Italy.

A proposal for a special curriculum in Water Engineering as a new branch of engineering was discussed in the early 80's, when the new University of Basilicata was being established in the city of Potenza. However this proposal was not approved by the CUN (see Art. 3.2.1) and in fact Hydraulic Engineering is still included as a syllabus in the Civil Engineering curriculum in the present teaching regulations (D.P.R. of May 20, 1989).

The collocation of hydraulic engineering within the frame of Civil Engineering conforms to the traditional policy of the Italian Engineering Faculties, which have always considered excessive specialization detrimental to the employment opportunities of the practitioners.

As a matter of fact, as can be seen from the typical study plan described in Art. 4.2.1, the syllabus in hydraulic engineering aims at affording a qualified training to people looking for employment in the public administration or in specialized firms and consulting bureaus active in the area of water engineering, as well as to prospective independent professionals in the same area. However the graduate in hydraulic engineering can also take advantage of working opportunities in other areas of Civil Engineering, since he or she has a fairly good background in structural and foundation engineering, and has shared the theoretical basis in mathematics and mechanics with the other syllabuses of Civil Engineering (and to a certain extent with the other branches of engineering as well).

Outside the traditional area of Civil Engineering, the study plan of hydraulic engineers has some points of contact also with the curriculum of Environmental and Territorial Engineering, in which some courses belonging to the groups named after « Hydraulics » and « Hydraulic and Marine Engineering » are included. This curriculum is presently operative in eight Engineering Faculties (Politecnico of Milan and Universities of Basilicata, Calabria, Ancona, Perugia, Salerno, Trento, Udine).