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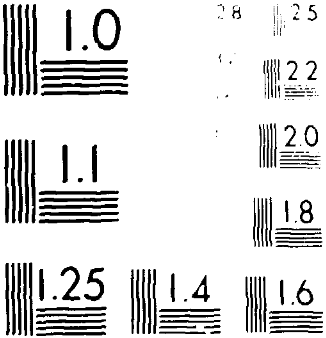

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ASSISTANCE TO MACHINE BUILDING INDUSTRY*

DP/CPR/79/021

CHINA

Technical report: Instruction and guidance in computer-oriented stress analysis at Zhengzhou Research Institute of Mechanical Engineering

Prepared for the Government of China
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Herbert A. Mang,
expert in computer-oriented stress analysis

United Nations Industrial Development Organization
Vienna

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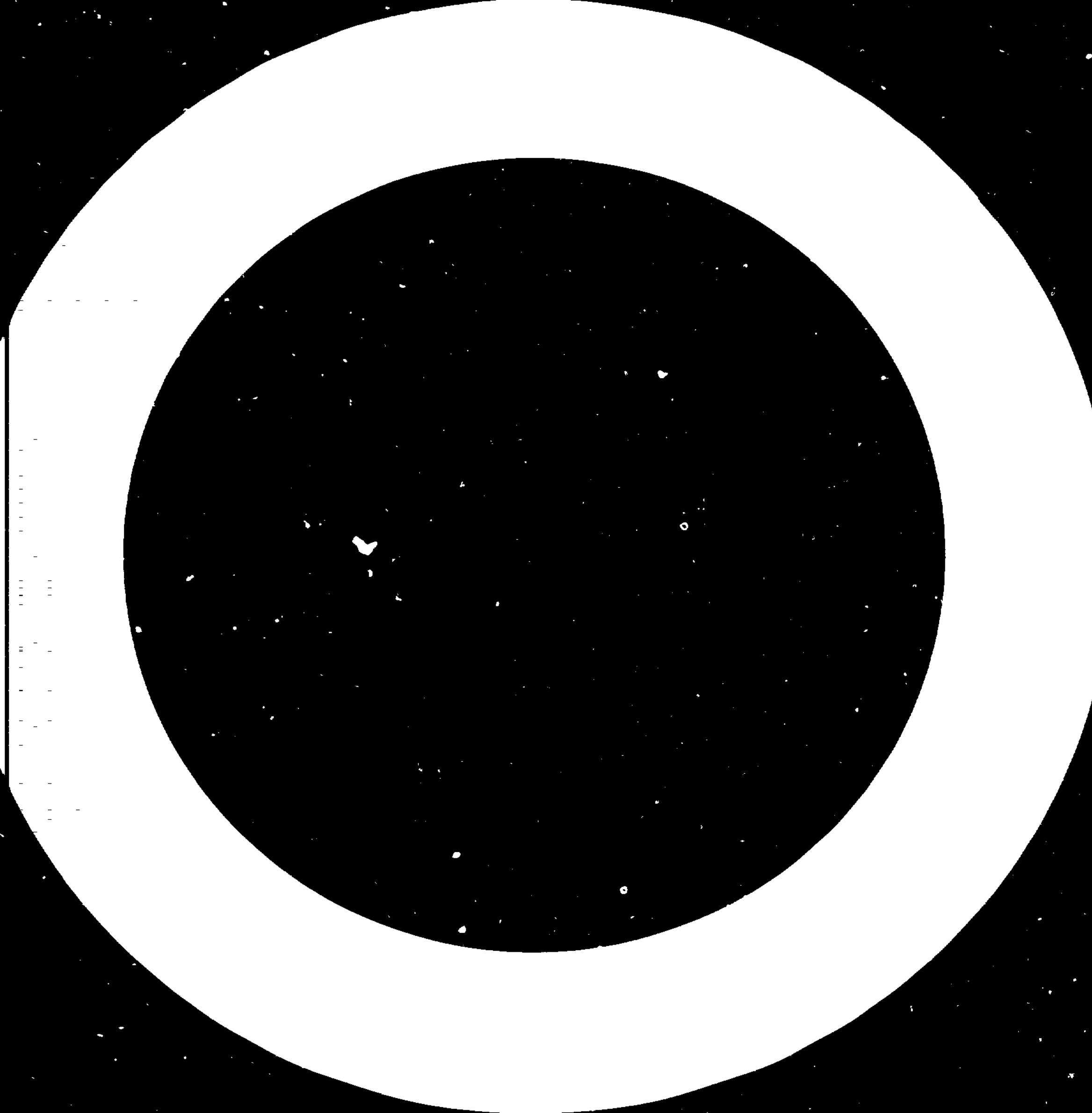
LIST OF CHAPTER AND SECTION HEADINGS



LIST OF ANNEXES

LIST OF TABLES

LIST OF FIGURES

NOTE PAGE

Value of local currency during the period of the project:

1 RMB YUAN 0.576 US $

Abbreviations (in alphabetic order):

ASME : American Society of Mechanical Engineers

BEM : Boundary Element Method

BFGS : Broyden-Fletcher-Goldfarb-Shanno

(names of scientists who developed a certain algorithm for solution of nonlinear algebraic equations)

FEM : Finite Element Method

FMMBI: First Ministry of Machine Building Industry

NTIS : National Technical Information Service

PRC : People's Republic of China

RD : Research Department

VDI : Verband deutscher Ingenieure

ZRIME: Zhengzhou Research Institute of Mechanical Engineering

Definition of specific technical terms (in alphabetic order):

Boundary Element Method: Numerical method based on discretization of the boundary of a given domain for algebraic solution of boundary integral equations.

Computer hardware: Computer equipment containing the central processing unit and the computer periphery.

Computer periphery : Subsystem of computer hardware for input and output of data.

Computer software : Programming subsystem of computer system.

<u>Crack-tip elements</u> : Finite-elements with in-built functions for consideration of stress singularity at crack tip.

<u>Data base</u> : More sophisticated concept than the older term "file". The important difference is that the data base must be stored in the computer on direct-access storage (such as disks) in order for the computer's central processing unit to be able to utilize the cross-references within a reasonable time.

<u>Data base management system</u> : Piece of software for managing data in direct access storage

<u>Finite element method</u> : Numerical method based on discretization of a given domain for solution of field problems

<u>Fracture mechanics</u> : Subfield of mechanics of solids concerned with determination of states of stress and strain in the vicinity of a crack-tip and of stability of cracks

<u>Incremental-iterative analysis</u> : Approach for solution of systems of nonlinear algebraic equations

<u>Isoparametric finite elements</u> : Finite elements based on a special form of coordinate mapping with the purpose of modelling curved surfaces of domains

<u>Lubrication potential</u> : Functional which yields the field equations and the essential boundary conditions of a lubrication problem as Euler conditions.

<u>Main-frame computer</u> : The main frame of a computer is the cabinet that houses the central processor and main memory. In this report, the term "main-frame computer" is used to distinguish a large computer from a minicomputer

Minicomputer : Computer which can broadly be classified as 8, 12, 16, 18, 24 or 32 bit word length machines with a memory size ranging from 4K to 256K provided in modules of 4K or 8K.

Optimum structural design : Optimum structural design seeks the selection of design variables to achieve, within the limits (constraints) placed on the structural behaviour, geometry, or other factors, its goal of optimality defined by the objective function for specified loading or environmental conditions.

Postprecessor : Data output module. In Finite Element Analysis, by postprocessing frequently the preparation of plot files for plotting deformed grids and producing stress plots as well as time-history plots is meant.

Preprocessor : Data input module which must transmit sufficient information to the solution and the output module so that the given problem can be solved. In Finite Element Analysis preprocessing includes generating a file of node coordinates with the help of a digitizer.

Quarter-point method : Consists of placing side nodes of quadratic, isoparametric elements at quarter points of sides in order to produce the desired stress-singularity at the crack-tip.

Rayleigh damping : A form of damping of vibrating structures in which the eigenvectors are orthogonal with respect to the damping matrix

Round robin test : Participants are asked to solve a certain problem (for example, by the Finite Element Method) for which no analytical results exists. Results are published by the organizers without cross-references between analysts and results.

<u>Slow stiffening</u> : A kind of stiffening of structures as it is found in geometrically nonlinear analysis of thin plates subject to bending.

<u>Stress-intensity factor</u> : A constant in the expressions for the displacement and stresses in problem of fracture mechanics. This constant depends on the magnitude of the externally applied stress.

<u>Sudden stiffening</u> : A kind of stiffening of structures as occurs, for example, for unloading of an elastic-plastic material.

ABSTRACT

Key words: boundary element method, computer hardware, computer software, computational mechanics, data base, finite element method, fracture mechanics, gears, lubrication, People's Republic of China, scientific instruction, stress analysis, vibrations.

The basic objective of the project was to assist the People's Republic of China in strenghtening its machinery building industry. This objective has resulted in specification of a number of duties for the UNIDO expert which can be summarized as providing instruction and guidance to engineers at the Zhengzhou Research Institute of Mechanical Engineering under the First Ministry of Machine Building Industry, in Zhengzhou, Henan Province, in the field of computer-oriented stress analysis (computational mechanics of solids).

Field work in Zhengzhou consisted of introductory discussions with senior counterpart staff on the present situation at the Research Institute, lecturing on the Finite Element Method (two weeks, six days per week, three times one and a half hours per day) and, to a small extent, on basic principles of Optimum Structural Design and of advising on scientific and/or technical problems posed by counterpart staff.

Conclusions and recommendations encompass qualitative and quantitative aspects of man-power, the computer and library situation, lecturing and research. The main conclusion is that the present computer situation at the Zhengzhou Research Institute represents an unsurmountable handicap for practice-oriented research in computational mechanics of solids. In full awareness of the financial implications, purchase of a powerful main-frame computer including appropriate computer periphery is strongly recommended.

INTRODUCTION

Project background

The Zhengzhou Research Institute of Mechanical Engineering (ZRIME) under the First Ministry of Machine Building Industry (FMMBI) of the People's Republic of China (PRC) was formed in 1971 in Zhengzhou, the capital of Henan province, by transferring one Department from another Institute, located in Beijing (Peking), to Zhengzhou. This town, with an area of 1,700 square kilometers and a population of 1.70 million (including the suburbs), is situated on the south bank of the Yellow River, east of the Sungshan Mountains, at the junction of the Longhai and Beijing-Guangzhou (Canton) railways. Henan Province with a total area of 167,000 square kilometers is located in Central China (see Fig.1). The population of Henan province is approximately 70 million.

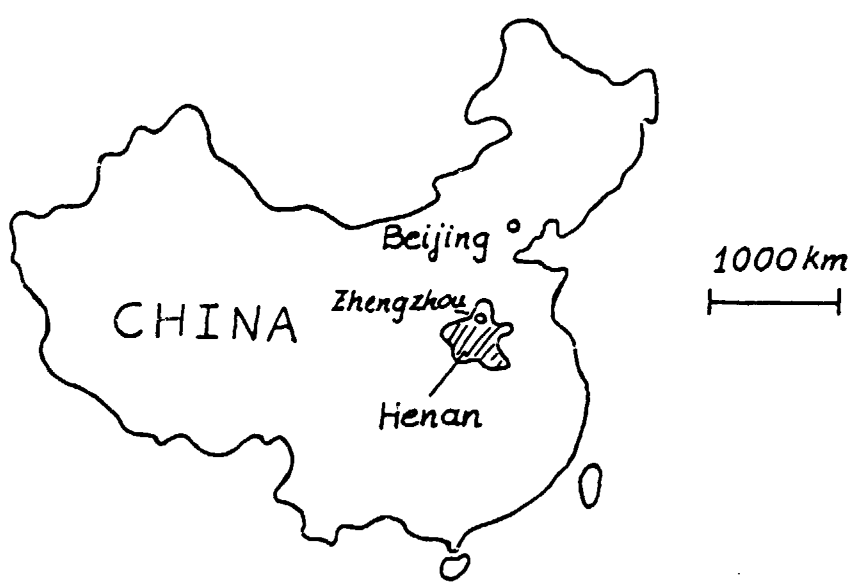


Figure 1 - Location of Zhengzhou, Henan Province

Henan province is one of the less developed provinces of the PRC. In spite of large efforts of the government of the PRC to speed up industrialization, the character of Henan Province is largely a rural one.

The Institute occupies a large site with many buildings, some still in the process of erection. Some of the buildings are not yet fully equipped.

ZRIME is divided into eight research departments, listed below:

(a) Structure Analysis Research Department (RD)

(b) Fatigue and Fracture RD

(c) Vibration RD

(d) Gear RD

(e) Casting RD

(f) Welding RD

(g) Heat Treatment RD

(h) Forging and Press RD

ZRIME employs about 800 persons, 195 of which are engineers, 76 are assistant-engineers and technicians, 19 are administrators and 94 are workers (The term "engineer" applies to individuals who have graduated from a university more than ten years ago and have proven ability for research work. "Assistant engineers" are persons who have graduated from a university within the last ten years. The designation "technician" refers to persons having graduated from a technical secondary school. Such persons may eventually be awarded the title "engineer" if, after a specified number of years working in the Institute, they demonstrate the ability to solve engineering problems independently). The remaining personel is distributed over several sections for various technical services including research management, power supply and equipment, technical intelligence and library, chemical analysis, etc. The plan is for the staff to total 1,000 by 1985 (Information concerning present distribution of personel in ZRIME and plans for future recruitment of additional man-power is provided in Chapter I).

The main task of ZRIME is solution of fundamental problems of mechanics of solids, primarily posed by the FMMBI, meeting requests of factories operating under the FMMBI. However, it is also possible for ZRIME to propose to FMMBI that a certain task be assigned to ZRIME.

Typical examples for practice-oriented research work conducted by ZRIME are determination of mechanical strength of equipment for power plants, mining and heavy machines as well as for mill and metallurgic industry. Questions have to be answered such as which material should be chosen for the blade of the hydraulic turbine for the Gezhouba power plant on the Yangtze River or which procedure should be employed for determination of profile modification and longitudinal correction for high-speed gears, used for compressors and turbo-machines, in order to maintain uniform loading and good lubrication conditions in operation. Problems must be considered such as which procedure should be employed for smelting the material for the afore-mentioned blade and how prot-air corrosion and fatigue in water would affect the material. Topics must be dealt with such as selection of reasonable geometric parameters for design of the blade and evaluation of the stiffness of the stator for the generator. Other questions which have to be answered refer to welding. For example, problems arising from thermal distortion caused by welding as well as questions related to saving of energy and increase of work-efficiency have to be tackled.

Furthermore, FMMBI has assigned the task to ZRIME to set up a Research Centre for Strength of Mechanical-Engineering Structures. The main task of this Centre will be to assist industry in increasing the level of product design in mechanical engineering. This task shall be accomplished by (a) solving complicated problems of mechanical strength for factories operating under the FMMBI and (b) training design engineers in these factories.

Presently, the standard of product design in mechanical engineering varies greatly. Improvement is especially important for factories of comparatively small size.

In order to fulfil the mentioned task, it is considered to be necessary to build up a data base containing information on (a) mechanical strength (admissible and ultimate values of strains and stresses and admissible values of displacements) and (b) computer programmes, primarily based on the Finite Element Method (FEM), for solution of complicated strength problems. This data base would also be made available to engineers in factories operating under the FMMBI.

Serving industry as well as accomplishing its own research goals, ZRIME has been and will be actively engaged in developing new as well as improving existing, commercially marketed software for computer-oriented strength analysis.

Objectives of the project

The original objective as stated in the Job Description for DP/CPR/79/021/11-12/31/9.B of June 10, 1980 was "... to assist the People's Republic of China in strenghtening its machinery building industry." This would "help to increase the productivity in the agricultural sector and thereby avoid a diverting of resources from the industrialization programmes to provide emergency measures to help feed the population adequately." This objective led to specification of the following duties for the UNIDO expert (stress analysis engineer) to be attached to the FMMBI:

(a) provide technical guidance and assist local specialists in carrying out research work in stress analysis technique using non-linear as well as linear methods,

(b) train local specialists.

At the end of August 1981, an updated Job Description was prepared by UNIDO. Deviations of the main objective of the project from the original objective were insignificant. Obtaining additional information from the field, it was possible to specify the duties of the field expert more precisely. According to the revised Job Description, these duties were:

"(a) provide instruction and guidance on the use of analytical and numerical methods for calculation of stress in structures;

(b) advise on the construction of mathematical models of structures for computer analysis of stresses;

(c) advise on optimal design of two-dimensional structures."

Moreover, "the expert was expected to spend about one week in lecturing to an audience of about 100, followed by questions and discussions." It was emphasized that all members of the audience would be knowledgeable in the subject and, consequently, "... there would be no need for lectures to start from the beginning."

After inspection of the computer situation at ZRIME, it became clear that the majority of tasks involving numerical analysis by the FEM could not be accomplished with the present hardware. This resulted in suggesting to senior counterpart staff that the cited list of duties be expanded to contain a fourth point, namely,

(d) advise on improving the computer situation.

This suggestion was well received by ZRIME.

Scope of report

The introduction is followed by the conclusions drawn from the expert's work at ZRIME. Thereafter, major recommendations are set out in descending order. The body of the report consists of four chapters, entitled "Present situation at ZRIME -- recommendations for improvement", "Organization of field work", "Lecturing" and "Research". The report contains several annexes including lecture notes prepared for ZRIME as well as lecture notes prepared for the Symposium on Mechanical Strength held by the Mechanical Design Division of the Chinese Society of Mechanical Engineers in Xi'an, Shaanxi Province, Nov. 3-9, 1981.

CONCLUSIONS

Conclusions drawn from the project are grouped in five sections: "Man power", "Computer", "Library", "Lecturing" and "Research". Only major conclusions from the individual chapters and sections, respectively, of the body of this Report are listed here. Conclusions of less general nature, as resulting, for example, from discussions of individual research topics are set out in the body of the Report and are not repeated here.

A. Man-power

Qualitative aspects

(a) The scientific level of many engineers at ZRIME with whom the expert has met is high.

(b) Because of the turmoil during the Cultural Revolution, many engineers did not obtain sufficient formal training. Most of their partially excellent knowledge on modern numerical methods such as the FEM and BEM was acquired by self-study. There appears to be a need for increasing the level of expertise of many engineers in these methods.

Quantitative aspects

In view of the amount of tasks assigned to the Structure Analysis RD, this Research Department is understaffed. This conclusion applies to the Programme Development Group and to the Computer Group of the Structure Analysis RD.

B. Computer

Hardware

(a) The present computer situation at ZRIME, characterized by a slow machine of the capacity of a minicomputer, represents an unsurmountable handicap for practice-oriented research in computational mechanics of solids.

(b) Lack of computer periphery at ZRIME such as a digitizer and a plotter makes efficient pre- and post-processing impossible. The FEM becomes unattractive if pre- and post-processing are inadequate.

Software

(a) The "mixed mode system" of programme development at ZRIME, characterized by writing special-purpose FE programmes while modifying existing, commerically marketed multi-purpose programmes, is both meaningful and effective.

(b) The need to travel to Beijing for use of the multi-purpose programmes on a machine with a FORTRAN compiler represents a handicap for efficient research in the field of computational solid mechanics.

C. Library

(a) With regards to technical journals from approximately 1976 up till now, the situation is much better than for earlier volumes.

(b) With regards to books, the situation is acceptable. Some of the pivotal books in computational mechanics are available.

D. Lecturing

(a) Preparation of lecture notes (after consultation with senior counterpart staff) increased the value of the lectures on the FEM, given at ZRIME, in October 1981.

(b) Preparation of transparencies for overhead projection proved to be very helpful for lecturing to an audience which can read

English quite well but has difficulties in understanding the spoken word.

(c) The audience seemed to be satisfied with the interpreter.

(d) Three lectures per day, each one lasting one and a half hours, as was the case with the above mentioned lectures, is too much because it does not leave enough time for solving example problems.

E. Research

General

(a) Many of the scientific problems discussed represent relatively high-level, up-to-date research in computational solid mechanics including the FEM and the BEM.

(b) The inadequate computer situation will make it increasingly more difficult for ZRIME to maintain or even improve the present level of research in computational solid mechanics.

(c) Restriction of scientific output to the "Chinese scientific market" because of language difficulties is a big problem. The number of foreign-language publications of researchers at ZRIME is very small. This is a pity because it prevents establishing scientific contacts with foreign colleagues.

Special (related to individual scientific problems discussed with counterpart engineers)

(see section B of chapter IV: Summaries of discussions of research topics)

RECOMMENDATIONS

Recommendations are grouped in the same manner as the conclusions, i.e. in 5 sections. Within each section, recommendations are set out in descending order. Only major recommendations from the individual chapters and sections, respectively, of the body of this Report are listed here. Recommendations of less general nature, as resulting, for example, from discussions of individual research topics are set out in the body of the Report and are not repeated here.

A. Man-power

Qualitative aspects

In order to increase the level of expertise of engineers at ZRIME in modern computational mechanics it is recommended to

(a) organize from time to time intensive, practice-oriented courses on various topics, such as the one on the FEM given by the expert in Oct.1981. Instructors should either be taken from the Institute or from other institutions within the PRC; resort to foreign experts should only be made if no Chinese experts are available;

(b) send a limited number of engineers with proven ability for high-level research to top-ranking foreign universities, encouraging them to enroll in formal degree-programmes. This permits control that the selected engineers use the given time optimally;

(c) send experienced engineers who did not receive sufficient formal academic education back to university to either enroll in graduate studies or take selected courses.

Quantitative aspects

In view of the volume and the importance of the tasks of the Structure Analysis RD, the number of staff of this Research Department needs to be increased substantially.

B. Computer

Hardware

(a) Purchase of a powerful main-frame computer is an absolute necessity for a Research Institute such as ZRINE. Such purchase is strongly recommended, in full awareness of the financial implications of this recommendation.

Purchase of a digitizer for efficient pre-processing and of a plotter for powerful post-processing in FE analysis is no less important than purchase of the main-frame computer itself. Therefore, it is strongly recommended to consider purchase of such computer periphery and to include its cost *a priori* in any feasibility studies concerning new hardware for ZRINE.

Software

(a) Increased priority should be given to development of pre- and post-processors for FE analysis.

(b) The task of "module control" should be assigned to an engineer with very good knowledge of computer hard- and software. This engineer would check developments of new programme modules written by other engineers. He would see to it that these modules are compatible with the existing programs.

C. Library

(a) It is recommended that direct contacts be established with foreign technical information services and publishing companies (some addresses are given in section C of chapter I).

D. Lecturing

(a) For courses similar to the one on the FEM given by the expert in October 1981, three weeks of lecturing (with three hours of lecturing per day) are recommended as the optimal course length, permitting the audience to devote sufficient time to the solution of example problems.

(b) It is recommended to organize a comprehensive course at ZRIME on the BEM, analogous to the course on the FEM. This would permit Chinese mechanical engineers to become more acquainted with a method which is presently second only to the FEM and which may be expected to gain additional momentum in the next future.

(c) Lecture notes should be prepared for the audience of courses similar to the course given by the expert at ZRIME. Modification of existing lecture notes of expatriate advisers should normally not start before personal consultation with senior counterpart staff.

(d) Preparation of transparencies for overhead projection is an absolute necessity for effective lecturing to an audience which can read English quite well but has difficulties in understanding the spoken word.

E. Research

General

(a) In order to maintain or even improve the present level of research in computational solid mechanics, purchase of a powerful main-frame computer and of computer periphery such as a digitizer and a plotter is strongly recommended (see also section B of the recommendations).

(b) Increased priority should be given to further development and application of the BEM.

(c) Scientists at ZRIME should be encouraged to publish the findings of their research in the international literature. Noting that a number of engineers and staff at ZRIME is fluent in English, it could be arranged that these individuals help improving the linguistic style of manuscripts of their colleagues.

Special (related to individual scientific problems discussed with counterpart engineers)

(see section B of chapter IV: Summaries of discussions of research topics)

I. PRESENT SITUATION AT ZRIME - RECOMMENDATIONS FOR IMPROVEMENT

This chapter consists of three sections entitled "Man-power: quantitative and qualitative aspects", "Computer hardware and software", and "Access to technical literature". Basic information on the topics covered in this chapter was obtained in a number of discussions with senior counterpart staff (for their names and positions, see annex 2) during the first days after arrival in Zhengzhou, on Sept. 14, 1981.

A. Man-power : quantitative and qualitative aspects

In the introduction basic information concerning man-power at ZRIME was given. Table 1 (see next page) contains the distribution of man-power over the previously mentioned eight Research Departments.

According to the objectives of the project, the expert's activities were mainly directed to the Structure Analysis RD. To a smaller extent, advice on mathematical models for stress analysis was given to members of the Fatigue and Fracture RD, the Vibration RD and the Gear RD. Because of lack of contact with representatives of other RDs no comments concerning possible over- or understaffing of these RDs can be made. The following comments on man-power are restricted to the Structure Analysis RD for which sufficient information is available.

In view of the tasks assigned to ZRIME, involving rather sophisticated, computer-oriented structural analysis, the Programme Development Group and the Computer Group are severely understaffed. Moreover, the number of engineers and assistant engineers and technicians shown in table 1 does not reflect the qualitative situation which is characterized by a shortage of engineers who can in fact develop new computer programmes, based on the FEM, or modify existing, commercially marketed FE-software. There is also a shortage of qualified individuals for

Table 1 - Distribution of man-power at ZRIME

		Engineers	Assistant Engineers and Technicians	Adminis-trators	Workers
Structure Analysis Research Department	Programme Development Group	7	5	-	-
	Computer Group	6		3	6
	Group for Experimental Stress Research	11	7	-	10
Fatigue and Fracture Research Department		22	14	2	13
Vibration Research Department		19	5	2	6
Gear Research Department		30	10	3	20
Casting Research Department		40	5	3	15
Welding Research Department		30	10	2	10
Heat Treatment Research Department		15	7	2	9
Forging and Press Research Department		15	5	2	5
Sum		195	76	19	94

advising engineers in factories on structural analysis, by the FEM, of machine parts.

The average age of the engineers in the Structure Analysis RD is about forty years. Because of the Cultural Revolution many of them did not obtain a sufficient amount of formal training. Graduate studies were re-introduced only three years ago. Formal academic degrees, following the Anglo-American pattern, were only introduced this year. In 1981, approximately 20,000 students for the entire spectrum of academic studies were admitted to graduate studies. Approximately 1,500 students were selected for pursuing studies in foreign countries. While this is certainly an improvement as compared to the situation a few years ago, a lot more needs yet to be done to meet the pressing needs of Research Institutes such as ZRIME.

With regards to computer-oriented numerical methods such as the FEM, there is a total of approximately ten engineers in the Structure Analysis RD who are competent in these methods. There are approximately ten more users of the FEM, distributed over several RDs. None of these engineers has obtained formal academic training in this method. They all acquired their partially excellent knowledge by self-study.

Since 1978 the FEM is taught at universities. The problem with university-level education is that it is not really practice-oriented. This is understandable because most universities are lacking powerful computer equipment. Moreover, universities consider themselves primarily as places for fundamental research. The main task of ZRIME, however, is to combine theory and practice for the purpose of more rational designs of machine parts.

As far as the Boundary Element Method (BEM) in concerned, only one or two engineers in the Structure Analysis RD have applied this method so far. Noting that the BEM is gradually obtaining world-wide momentum, it is suggested that more emphasis be laid on the BEM in future and that studies be undertaken, which aim at combining the FEM and the BEM for selected applications.

The level of expertise in modern numerical methods at ZRIME can be increased by

(a) <u>sending qualified engineers back to university to engage in graduate studies</u>
(provided courses on the FEM, the BEM, Numerical Analysis, Computer Programming, etc., are offered)

(b) <u>organizing intensive, practice-oriented courses within ZRIME</u>
(with instructors being taken either from the Institute or from other institutions within the PRC; resort to foreign experts should only be made in exceptional cases, that is, if no Chinese experts are available)

(c) <u>sending a limited number of engineers with proven ability for high-level research to top-ranking foreign universities</u>
(encouraging them to enroll in a formal degree-programme so as to exercise control that the selected engineers use the given opportunity optimally; the best effort should be made to choose only engineers with adequate knowledge of the language of the host country for studies abroad; arrangements with the host university concerning sufficient access to the computer facilities should be made in advance)

It should be avoided to over-emphasize anyone of the three listed modes for improvement of the level of expertise in modern numerical methods at ZRIME.

Mode (a), for example, would obviously not be effective if there was a shortage of instructors with practical (computer) experience in the FEM and the BEM, respectively. Most textbooks currently available emphasize the basic theoretical aspects of these methods, with applications being presented to demonstrate the essentially practical nature of these techniques. However, there is an enormous gulf between the basic theory and a working computer code: it is now widely acknowledged that the programming involved in implementing finite elements is considerably more complicated than that of finite differences.

Provided qualified instructors can be recruited, mode (b) is probably most effective because it reaches everybody in the Institute who feels the necessity to improve his level of competence in the FEM and the BEM, respectively. It is widely acknowledged in the industrialized countries that intensive, practice-oriented courses, given at companies or research institutes, are more effective than many standard university courses. Often, the amount of material covered in the former courses in a relatively short time-span is equivalent to what is covered at universities in a semester. In this context, it must be borne in mind that the audience in courses on the mentioned special topics is usually more mature than young students at university.

Instruction without visual aids such as transparencies for the overhead-projector is of limited value. Preparation of lecture notes by the instructor is indispensible. Sufficient time should be given to the participants in the courses for study of the underlying theory and solution of skillfully designed example problems. Assuming that mornings are reserved for lecturing (say, two lectures, one and a half hours each), whereas afternoons and evenings are used for studying and solving of example problems, a period of approximately three weeks seems to be optimal. The amount of material which can be covered by the instructor during this time would exceed what is covered at most European and American universities in a whole semester.

While modes (a) and (b) of increasing the level of expertise in computer-oriented numerical methods are adequate vehicles for improving the overall standard, mode (c) is obviously best suited for highly talented engineers with demonstrated research ability. It is neither possible nor advisable to send large numbers of research workers to foreign universities. Apart from financial constraints, the question needs to be answered whether the Chinese researcher at a foreign university will necessarily find what he has expected.

Noting that computer-oriented research in the FEM or the BEM is man-power intensive, it is understandable that senior professors are eager to hire graduate students who are usually performing the bulk of the programming work. Quite often, this tedious work represents the student's main contribution to a research project. The student's reward usually is a higher academic degree. Thus, the professor is interested in the student's work who in turn is interested to satisfy the professor. With regards to so-called research associates or research scholars who do not work for an academic degree, the situation occasionally turns out to be rather problematic, especially if the scholar's financial support does not come from the university. The worst case that may happen is lack of mutual interest between the professor and the research scholar. Based on his own observations in Europe as well as in the USA, the writer suggests that Chinese students selected for research work at foreign universities be encouraged to enroll in formal degree programmes. (Obviously, this suggestion does not apply to senior researchers with an established reputation in research).

When planning studies abroad, it should be kept in mind that many universities charge money for computer services made available for scientific projects. Although there are frequently possibilities to obtain a certain amount of computer time free of charge if proof of the importance of the project can be given, the writer's personal experience coupled with information from several discussions with American colleagues has been that computer time may be a severe problem at many American institutes of higher learning. Public (State) universities in the USA usually find it easier to provide faculty and students with ample computer time than is the case with certain private universities.

It follows that Chinese researchers in the area of the FEM, planning to pursue studies or research work abroad should request detailed information about computer facilities at the prospective host institute . It is not sufficient to collect information about the type of available equipment. Information concerning the conditions for use of the respective computer facilities is necessary. Researchers who intend to conduct nonlinear studies of structures encountered in practical mechanical engineering should make sure that funds for performing such studies will be available to them.

The preceding suggestions referred to qualitative improvements of the level of competence of research workers engaged in computer-oriented numerical analysis. However, given the amount of tasks assigned to the Structure Analysis RD as well as to other RDs of ZRIME, a quantitative improvement on the sector of man-power is indispensible. In view of the importance of a strong Programme Development Group for developing or improving software as well as for serving industry, a substantial increase of man-power in this Group is necessary. The same would apply to the Computer Group if a powerful main-frame computer (representing an absolute necessity, as will be seen in the following section) was installed at ZRIME.

It is planned to set up a Data Base Group of about fifty people. The task of this Group would be to build up the data base mentioned in the Introduction. Considering the great importance of setting up a date base containing information on mechanical strength and on FE-software, the mentioned number of people is certainly not too high.

B. Computer hardware and software

Hardware

ZRIME has a Chinese computer, TQ 16, with a memory size of 32 K, four external drums and two independent tape drives. This machine performs 10^5 operations/second. It was obtained in 1975. In addition, there is a new French computer/data processor, Intertechnique Prolimat S Multi, with a memory size of 64 K. This computer is mainly used for vibration analysis. According to table 1 on page 931 of the Encyclopedia of Computer Science (1), the memory sizes of both machines are comparable to the memory sizes of minicomputers.

Discussions with researchers at ZRIME reveal that the TQ 16, which is used for FE-analysis, is very slow. For example, it would take 20 minutes for linear analysis of a system with approximately 2,000 degrees of freedom but with the rather small half-band width of only 40. For an axisymmetric, elastoplastic problem with 576 degrees of freedom, it would take 3-4 hours (no information on the half-band width of this problem was available). For solution of a plane problem of elasto-plastic fracture mechanics with 318 degrees of freedom and a half-band width of 36, ten hours (!) of computer time were required.

In the Fatigue and Fracture RD only 3-4 people are able to use the computer. Consequently, at present, 10 hours of computer time may be acceptable. However, the situation will change dramatically if the percentage of people who are familiar with the computer increases substantially. The fact that the computer runs only during regular working hours shows that, presently, demand is not too high.

In this context, it should be borne in mind, however, that inadequate computer facilities distort the true situation. For example, there are engineers at ZRIME travelling to Beijing for solution of problems requiring hard- and software not available in Zhengzhou. For obtaining computer plots it is necessary to go to Hangzhou.

Such a situation may be acceptable for some time so long as there is little demand of computer power. However, in view of some of the previously mentioned tasks assigned to ZRIME, demand of computer power will increase substantially in the next future.

It will be nearly impossible for ZRIME to meet some of the tasks assigned by FMMBI unless the computer situation is improved dramatically. By "dramatic improvement" installation of a large main-frame computer is meant. Being fully aware of the financial implications of this "trivial" recommendation, it needs to be emphasized, that the necessary "dramatic improvement" cannot be achieved in a "minicomputer environment", given the capacity of even the largest minicomputers presently available.

The situation would be somewhat different if a dense net of powerful main-frame computers, distributed over the PRC, was available. In this case, minicomputers could communicate with the main-frame computers. For such communication, standard telephone lines could be used. However, even if the mentioned dense net of main-frame computers existed, and the telephone net permitted the indicated communication, it would not be acceptable for a leading Research Institute of a country with approximately a billion people to rely on a minicomputer serving as an intelligent terminal to an out-of-house main-frame computer.

At present, the number of powerful main-frame computers in the PRC is very small. Table 2 (see next page) gives a rough overview over the distribution of large computers in the PRC. This table was prepared by counterpart staff on request by the expert.

In spite of the fact that the table is incomplete, nevertheless, it is quite instructive. It reveals that (a) the overall number of large main-frame computers is very small (even if this number is in error by a factor of 2-5) and (b) computer power is concentrated in the Capital City of the PRC. In this context, it should be mentioned that there is no large main-frame computer in Henan Province. The same applies to three provinces South of Henan Province. These three provinces and Henan Province have a total population of more than 200 million (!) people, approximately the same as Great Britain, the Federal Republic of Germany, France and Italy together.

In order to reach the goals of the "Four Modernizations of the PRC", every effort must be undertaken to improve the situation on the computer sector. In the absence of any large main-frame computer in Henan Province (with a population equal to the one of the Federal Republic of Germany and Austria together), it is unrealistic to expect that present-day minicomputers will be able to solve the problem of lack of computer power in Research Institutes such a ZRIME.

It also needs to be mentioned that there is a lack of FE-software running on minicomputers. In a lecture, given this year in Hefei, Anhui Province, Wilson (2) mentions "... that the availability of software only exists for large computers. Within the next ten years", he continues "this problem should be eliminated and small, inexpensive

Table 2 - Distribution of large main-frame computers in the PRC
(Note that this table is incomplete)

Place: City	Place: Province	Computer Type	Capacity	Speed (operations/sec.)
		IBM 370/138	512 K	3×10^5
Shen-yang	Liao-ning	IBM 4331	1,024 K	5×10^5
		FELIX-C-256	256 K	2×10^5
Chang-chun	Jilin	EC 1040	512 K	3×10^5
Hang-zhou	Zhe-jiang	Siemens 7738	512 K	3×10^5
Nan-jing	Jiang-su	Siemens 7738	512 K	3×10^5
		IBM 370/138	512 K	3×10^5
		FELIX-C-256	256 K	2×10^5
		EC 1040	512 K	3×10^5
		IBM 4331	1,024 K	5×10^5
Beijing		CDC ?	1,024 K	?
		CDC ?	1,024 K	?
		ACOS 500	1,750 K	?
		CDC ?	?	?
		FELIX-C-256	256 K	2×10^5
		IBM 4341	?	8×10^5
		Wang-An	?	?
Zhuo-xian	Hebei	CDC ?	?	$>10^6$
Shanghai		IBM 370/148	1,024 K	5×10^5
Shanghai		ACOS 400	512 K	3×10^5
Chengdu	Sichuan	ACOS 400	512 K	3×10^5
Wuhan	Hebei	Wang-An	?	?

Countries of origin of less known computers: FELIX (Romania), EC (East Germany), ACOS (Japan), Wang-An (China) computer systems which can communicate over standard telephone lines with other computer systems should allow small engineering firms to have the same computational power as now exists in large firms." This sentence reveals that Wilson is primarily concerned with the needs of small (private) engineering firms. This becomes obvious from sentences such as (2) "...the existing computer programmes were not developed with the needs of the small user in mind" and "... at this time it is desirable that new programmes address the needs of small engineering offices."

Wilson's statements are correct. His recommendations are appropriate. However, with regards to ZRIME which is considered to be the leading Institute in China under FMMBI in the field of stress analysis, recommendations which fit small Western engineering firms cannot be adopted.

Small engineering firms in the fields of Mechanical and Civil Engineering are predominantly engaged in linear structural analysis. They usually can afford a relatively slow turn-around in data processing because of limited demand of computer power. Obviously, the situation is markedly different with a large Research Institute such as ZRIME. The percentage of nonlinear analysis carried out by ZRIME is probably higher than the percentage of such analysis performed by small engineering firms. Following the international trend in pertinent research, it should be expected that the percentage of nonlinear analysis conducted at ZRIME will increase rapidly within the next years.

For a developing country such as the PRC, the question comes up how to improve the present computer situation most effectively considering the existing financial constraints. It is unrealistic to expect that all research institutes, universities and major factories engaged in large-scale FE analysis will obtain sufficient funding for purchase of adequate main-frame computers. What would seem to be more realistic is to concentrate, at least for some time, high-level research in the FEM and the BEM in selected research institutes such as ZRIME, considering available expertise, computer power (existing or projected for the near future)and appropriate regional distribution. These pivotal institutes could be future communication centres for smaller institutes which could gradually be equipped with minicomputers.

It is highly desirable that engineers and scientists in top ranking Research Institutes such as ZRIME participate in the development of FE-software for minicomputers. However, it would be wrong to concentrate all efforts on development of such software (which requires more sophistication in computer programming than development of FE-software for large main-frame computers) while industry faces the pressing need for instant application of the FEM to complicated linear and nonlinear problems of stress analysis in mechanical engineers.

It is re-emphasized that ZRIME will neither be able to provide adequate service to industry in computer-oriented large-scale numerical analysis of machine parts nor will it be able to reach its scientific goals in further development of the FEM or BEM, especially with respect to nonlinear analysis (at least, not without substantial delays in time), unless the Institute is equipped with an adequate main-frame computer. Trivial as this statement may seem, it nevertheless reflects the most important finding of the expert's mission at ZRIME.

Finally, a comment on peripheral equipment seems to be appropriate. Evaluation of results from FE-analysis may be a tedious and time-consuming process. This is especially true for nonlinear and transient analysis. Checking of input data, which is indispensible in FE-analysis, is also tedious and time-consuming. These factors are responsible for the fact that many engineers shy away from applying the FEM. For practice-oriented FE-analysis, graphical displays of the FE-mesh and of selected results represent a necessity. It is unacceptable (and practically impossible) to study the voluminous output of a large-scale nonlinear analysis which is performed in an incremental-iterative way. Errors in lengthy lists of input data may easily be overlooked. Thus, the actual analysis would be started with incorrect input data.

Expensive modes of computer graphics such as interactive graphics emphasizing man-machine dialog are not recommended. What is strongly recommended, however, is off-line input of node points of FE-meshes via a digitizer and output of drawings (FE-mesh, displacements, principal stresses, iso-stress lines, contours of plastic domains, time-histories of stresses, temperatures, etc.)via a plotter. If purchase of a main-frame computer is considered it would be wrong to save on essential computer periphery.

<u>Software</u>

ZRIME has access to two commercially marketed programme systems, SAP and ADINA. Both programmes were purchased by FMMBI (SAP in 1978 and ADINA in 1980). Since the TQ 16 computer at ZRIME has no FORTRAN compiler, engineers of ZRIME who wish to use these programmes must travel to Beijing. Obviously, this is not an ideal situation.

SAP, restricted to linear analysis, and ADINA, having the capability for nonlinear analysis, are well-established, reliable programmes. Both are characterized by high-level computer-programming technology. Expectedly, a few of the more expensive multi-purpose computer programmes than ADINA have significantly larger capabilities than ADINA. This refers especially to the range of nonlinear analysis. A good survey of structural mechanics computer programmes based on the FEM was prepared by Fredriksson and Mackerle (3). From time to time their original work is updated.

During the last years ZRIME was active to modify SAP and to prepare prepocessors, respectively. Work on "4-9 Node Finite Elements", "Boundary Elements", "Linkage Elements" (that is, connecting elements between different types of elements) has been completed. Moreover, "Substructuring" was implemented.

With regards to ADINA, the Programme Development Group of the Structure Analysis Research Department at ZRIME is in the phase of getting accustomed to this programme. Thereafter, work on modifications will be taken up.

In addition to modification of commercially marketed multipurpose FE computer programmes, since 1976 a number of special purpose programmes was developed by the Programme Development Group. The computer language used was BCY which is similar to ALGOL. Use of BCY was dictated by the compiler of the Institute's computer. Table 3 contains a list of the FE computer programmes developed at ZRIME. This list reflects a relatively wide field of activities.

The "mixed mode system" of programme development, which has been implemented at ZRIME, is useful and effective. At the writer's home institute, the Technical University of Vienna, this system has proved to be successful.

Development of special programmes helps to increase the level of compentence of engineers working in this field. Moreover, such programmes can be taylored from the very beginning of their development to the special needs of users at ZRIME.

Table 3 - List of FE computer programmes developed at ZRIME

No.	Designation	Characteristics	Date of Development
1	General Programme for Plane and Axisymmetric Problems	2-D Variable Band-Width Storage Triangular Elements	1976
2	General Programme for Plane and Axisymmetric Problems with Eight-Node Isoparametric Element	Solution in Blocks 1-D Variable Band-Width Storage	1977
3	General Programme for Plane and Axisymmetric Elasto-Plastic Problems	Ideal Plasticity; Arbitrary Curve Hardening; von Mises Yield Criterion	1976
4	General Programme for Space-Frames with Special Joints	1-D Variable Band-Width Storage; for Machine Frame Analysis (Including Truss, Beam)	1976
5	Programme for Two-Dimensional Fracture Mechanics (K_I, K_{III})	Elements with Inbuilt Crack-Tip Singularity (Wilson's Element)	1976
6	General Programme for Two-Dimensional Elasto-Plastic Contact Problems	Mixed Co-ordinate System; Iteration in Contact Region Onl	1978-1979
7	Programme for Contact Problems of Structures Consisting of Plates and Beams	Frontal Solution; Substructuring	1978-1980
8	Programme for Three-Dimensional Fracture Mechanics (K_I)	Quarter-Point Elements for Crack Tip Singularity	1979

Multi-purpose programmes, on the other hand, facilitate the task of serving industry. It would be problematic for ZRIME to develop a new multi-purpose programme system. First of all, a relatively large number of such programme systems is available on the market for many years (3). In spite of some justified criticism on existing programmes, as was raised, for example, by Wilson (2), most of these programmes obviously serve the needs of their users irrespective of the unchallenged fact that the employed finite elements, the used numerical techniques and the provided facilities for input and output of data are more or less outdated.

Chances are that already at the time of planning a new in-house development of a multi-purpose FE programme system certain software components as they are planned, represent out-of-date software technology either because of no access to the latest developments in this field or because of lack of pertinent experience.

With regards to development of new or modification of existing FE computer programmes, at Technical University of Vienna it has turned out to be useful to assign the task of "module control" to an engineer with very good knowledge of computer hard- and software. This engineer checks developments of new programme modules, written by other engineers. He sees to it that these modules meet the requirements of the existing programmes. Collaboration of this specialist with the group of "software engineers" has proved to be beneficial to the modularity of the FE computer programmes developed at Technical University of Vienna.

With suitable modifications, the outlined strategy for improvement of FE computer programmes may also be useful for the Programme Development Group at ZRIME.

C. Access to technical literature

Library

Access to technical literature is primarily provided by the library. The library contains about 100,000 volumes (books and journals, the latter bound to annual volumes). Approximately 70,000 volumes date back to the period from 1956 - 1971, that is, to the time before forming ZRIME. The library is organized such that Chinese technical literature is distributed over one floor of the Institute and foreign technical literature is distributed over the other one.

There are nine rooms reserved for foreign technical literature including a room for reading. This room contains the latest numbers of foreign journals. Table 4 shows the distribution of foreign journals according to languages:

Table 4 - Distribution of foreign journals according to languages

Language	Number of journals
English	220
Japanese	75
German	34
Russian	25
French	8

The predominance of English technical literature reflects the worldwide acceptance of English as the linguistic medium for scientific communication. The ratio of English-language journals to other foreign-language journals is not unreasonable.

Volumes (from approximately 1976 up till now) of major technical journals in the fields of expertise of the writer are available.

With regards to books, much effort is made to obtain relevant literature in all fields of interest to ZRIME. Books are ordered via the China Book Import-Export Company, located in Beijing. From this company,every month ZRIME obtains information on new books. In order to get a rough idea of books available in the library, a check was made of how many of the 24 books which the writer had shipped to China were available. The result of this check was: 9 books available and 15 books not available (For details of this check, see annex 3). It should be noted, however, that a total number of 24 books, restricted to a couple of scientific fields within mechanics of solids, is too small to make reliable extrapolations concerning the overall availabity of foreign technical literature in the library of ZRIME.

From his discussions with staff at ZRIME the writer has won the impression that there is general awareness of the importance of access to modern foreign technical literature. It is felt that the responsibility for further improvement of the standard of the library should be shared, perhaps to a larger extent than now, by all research-workers of ZRIME. The following Subsection contains a few simple suggestions in this respect.

Direct contacts with foreign technical information services, publishing companies and individual scientists

Quite frequently, it is most efficient to contact a foreign technical information service, publishing company or an individual scientist directly. This should not be misinterpreted as the recommendation to bypass central authorities. For example, literature searches, often indispensible when entering into a new field, could be arranged directly with the National Technical Information Service of the U.S. Department of Commerce, Washington, D.C.,USA. Dissertations, frequently containing a wealth of useful material which may never appear in the open literature, could be ordered directly from University Microfilms, Ann Arbor, Michigan, USA.

An economic method for Research Institutes such as ZRIME to buy English-language technical literature would be to join the American Society of Mechanical Engineers as a Collective Member. ZRIME would then become eligible to join so-called Book Clubs, established by the McGraw-Hill Publishing Company, New York, USA. Members of such Book Clubs obtain monthly information of literature which is sold at discount prices. (The discount occasionally is up to 50 % of the original prize). Most of the books advertised have only been published a couple of years ago. Some of the books represent older, "classical" literature in the respective field.

(Note that the given addresses are incomplete because street names and numbers and postal codes are missing. It should be no problem to obtain the missing information, for example, from the Embassy of the United States of America in the PRC, Beijing, 2 Xiushui Dong Jie, Jianguomenwai; Tel. No. of the Cultural Section: 52-36-45)

Trivial as this recommendation may seem to be, engineers at ZRIME should be encouraged to contact their colleagues all over the world directly, if they need a specific Research Report. Over the years, the writer has made the pleasant experience that nearly all of his quests for such reports were met. Rather frequently, the offer of re-imbursement of expenses was flatly refused by the contacted colleagues. Sometimes a relatively small charge for postal expenses was made. Usually, scientists consider it as an honour if their reports are requested from colleagues all over the world.

II. ORGANIZATION OF FIELD WORK

After completion of initial discussions with senior counterpart staff, a detailed work plan was set up according to the expert's duties at ZRIME, listed in subsection "Objectives of the project" of the introduction. After minor modifications by senior counterpart staff, the revised work plan was approved by ZRIME. As work on the expert's assignment was progressing, a couple of small changes of the revised work plan became necessary. The final organization of field work is documented in annex 4.

The activities in the field were divided into two main categories, namely, (a) lecturing and (b) teaching.

By the term "lecturing", a formal course on the FEM as well as a series of "special lectures" and two presentations at the Symposium on Mechanical Strength held by the Mechanical Design Division of the Chinese Society of Mechanical Engineers in Xi'an, Shaanxi Province, Nov. 3 - 9, 1981, are meant.

By the term "research", instruction and guidance to individual researchers or research teams at ZRIME according to point (a) of the revised Job Description and advice to such research teams according to points (b) and (c) of the revised Job Description are meant.

Chapter III covers "lecturing" and chapter IV covers "research".

III. LECTURING

A. Motivation for offering a formal course on the FEM

The Job Description (see Subsection "Objectives of the project" in the Introduction) mentions lecturing but does not go into much detail concerning specific topics of the lectures. In the following, the motivation for offering a formal course on the FEM will be given.

The Structural Analysis RD, the Fatigue and Fracture RD, the Vibration RD and the Gear Transmission RD either are or plan to be engaged in computer-oriented numerical analysis. Typically, the analysis should satisfy two purposes, namely, (a) checking the usefulness of the selected analysis model and the correctness of the applied computer programme by comparing the results to information obtained from tests, and (b) performing numerical parameter studies. The purpose of the latter is to study the influence of a variation of parameters such as the shape of the analyzed structure or structural component, the boundary conditions, the material properties, the loads, etc., on the results. Provided that the first purpose is met, usually no need arises to plan and conduct lengthy test series and, finally, evaluate the test results.

Restriction of testing to the necessary minimum, that is, to verification of analytically obtained results permits saving of time and man-power. Although it seems that at present in the PRC these two factors do not play such an important role as in the most developed countries, the situation will probably change in the future.

The question whether the outlined philosophy for research in applied mechanics of solids is the most economic one can be answered affirmatively as far as developed countries are concerned. With respect to developing countries such as the PRC the high cost for purchase of powerful computers may distort the situation for some time. On the longer run, however, there should be no doubt that the described mode of research is more economical than a predominantly test-oriented mode of research.

With regards to ZRIME, it is necessary that more scientists and engineers become familiar with the FEM and the BEM. Concerning applications of mechanics of solids to complicated practical problems in mechanical engineering, these two methods account for the vast majority of numerical analyses in the mentioned field.

Out of the two methods, the FEM is unquestionably dominating. The reason for this is the greater generality of this method as compared to the BEM. Nevertheless, the latter is gradually gaining momentum. This refers especially to nonlinear analysis which, still a few years ago, was considered to be the sole domain of the FEM. Since in case of the BEM the algebraic equations describing the discretized model of the structure to be analyzed involve only points on the boundary of the structure, the number of algebraic equations to be solved is usually significantly smaller than the corresponding number for the FEM. On the other hand, application of the FEM often results in a narrowly banded system of equations whereas the BEM usually yields a full coefficient matrix.

In the opinion of the writer it is impossible to make generally valid statements concerning the relative efficiency of the two methods. The present situation in industry in some of the most developed countries is characterized by the dominating role of the FEM. Considering the large financial efforts made by industry in order to shape the FEM to become the leading numerical method, it is unlikely that the near future will bring about a change of the present situation.

This was the main motivation for proposing to senior counterpart staff that a formal course on the FEM should be given. Moreover, it was suggested that this formal course should be followed by a series of special lectures on selected topics of the FEM and of introductory lectures on Optimum Structural Design.

B. Contents of lectures

Lectures on the FEM

The contents of the lectures on the FEM was determined as follows: a list of contents (in English-language) of the expert's German-language lecture notes on the FEM as well as the lecture notes themselves were given to senior counterpart staff. The list was returned to the expert with classifications of chapters, sections and subsections, respectively, of the lecture notes as A (less material needed for lectures at ZRIME), B (amount of material in German-language lecture notes just about right for lectures at ZRIME) and C (additional material required for lectures at ZRIME). Annex 4 contains the mentioned list of contents with the indicated classifications.

In view of the large amount of material to be covered in the lectures, it became necessary to increase the percentage of lecturing in the expert's overall assignment. For the lectures on the FEM, two weeks (six days per week) were reserved. For each day, three lectures (one and a half hours each) were planned.

On the basis of the mentioned "weighted" list of contents (see annex 5) as well as of the available time (see annex 4), hand-written lecture notes, which were mimeographed for the audience (see annex 7), were prepared. The chapters covered in these notes are:

(a) Introduction to the Finite Element Method (26 pages)

(b) Use of variational calculus for derivation of equations of motion for a discretized, three-dimensional, linear-elastic continuum (29 pages)

(c) Plates (plane stress and strain, respectively) (36 pages)

(d) Axisymmetric solids (16 pages)

(e) Three-dimensional problems (3 pages)

(f) Flexure of thin slabs (43 pages)

(g) Thin shells (35 pages)

(h) Steady-state field problems (11 pages)

(i) Geometric and physical nonlinearity (32 pages)

Special lectures

A list of contents of special lectures on selected topics of the FEM and of introductory lectures on Optimum Design was given to senior counterpart staff (see annex 6). This list contained the titles of ten lectures, up to six of which could be selected by ZRIME for special lectures distributed over three half-days (two lectures per half-day, each lecture scheduled to last one and a half hours).

The following lectures were chosen by ZRIME:

(a) Buckling of thin shells subjected to follower-load forces of the form of hydrostatic pressure

(b) Ultimate load analysis of cracked reinforced-concrete plates, slabs, and shells considering geometric and physical nonlinearity

(c) Wind-loaded reinforced-concrete hyperbolic cooling towers: buckling or ultimate load ?

(d) Constitutive equations for plasticity and creep

(e) Introduction to optimum structural design

(f) Introduction to fully stressed design

Hand-written lecture notes, which were mimeographed for the audience (see annex 8), were prepared. The lecture notes only cover items (d) - (f) which were considered to be especially important to ZRIME. The notes are based on material by Gallagher (4,5,6).

Item (a) is covered in lecture notes (see annex 9) prepared for the previously mentioned Symposium in Xi'an. For items (b) and (c), transparencies for overhead-projection were a priori available.

Lectures at Symposium of Mechanical Strength, Xi'an, Nov. 3-9, 1981

FMMBI and ZRIME made preparations for the expert to lecture at the above Symposium on the topic: "The Finite Element Method - an indispensible tool for stress analysis in mechanical engineering." Hand-written lecture notes, which were mimeographed for the audience (see annex 9), were prepared.

C. Mode of lecturing

Because the majority of the audience was expected to have difficulties following lectures held in English, ZRIME provided two interpreters(one for the first week and one for the remaining time) for lecturing. The lecture notes were given to the interpreters in advance, permitting to prepare in time for the coming lectures. The interpreters met with the expert every day to discuss the topics of lectures to be held on the following day.

Many Chinese engineers who find it difficult to express themselves in English can read quite well in this language. This fact suggested that, in addition to the lecture notes, transparencies for overhead projection be prepared.

It is felt that the combination of (a) speaking slowly and pronouncing exactly, (b) having the spoken word translated into Chinese, (c) using the overhead-projector and (d) handing out lecture notes to the audience is a suitable mode of lecturing under the given circumstances.

D. Findings

(a) Feedback from the audience, both directly and via the interpreters, gave the impression that the level of the lectures was "just right".

(b) The audience seemed to be satisfied with the interpreters.

(c) Preparation of lecture notes increased the value of the lectures for the audience.

(d) Preparation of transparencies for overhead projection proved to be very helpful for lecturing to an audience which can read English quite well but has difficulties in understanding the spoken word.

(e) Although the audience did not complain, the expert felt that three lectures per day, each one lasting one and a half hours, was too much for some participants.

(f) Regrettably, there was not enough time available for the audience to solve example problems which would be posed by the instructor in the form of "homeworks". It takes a few hours to "digest" the contents of three lectures per day. Consequently, it cannot be expected that on top of this time the participants spend several hours working on homework problems. (For completeness, it should be mentioned that after the end of the course, a couple of example problems for calculation by hand were prepared for the participants of the lectures. At the time of preparation of this report, there was only a small return of solved problems. In this context, it must be borne in mind, however, that near to the end of the calender year, engineers at ZRIME must see to it that their regular research assignments be completed in time.)

(g) Although the expert encouraged the participants to interrupt him if they instantly wanted some information, such an interruption never happened. The reasons for this are probably twofold, (i) the language problem and (ii) the natural courtesy of the Chinese. Interruption of a lecturer seems to be incompatible with good manners.

E. Recommendations

(a) Lecture notes should be prepared for assignments similar to the one of the expert at ZRIME. However, modification of existing lecture notes should not start before personal consultation with senior counterpart staff, that is, before arriving in the field.

(b) Preparation of transparencies for overhead projection should be considered as an absolute necessity.

(c) For courses similar to the one given by the expert at ZRIME, three weeks of lecturing (with only three hours of lecturing per day) should be considered as the optimal course length. This would permit the audience to devote more time to the solution of example problems.

(d) A comprehensive course on the BEM, analogous to the one on the FEM, should be given at ZRIME or another suitable Research Institute under the FMMBI. This would permit Chinese mechanical Engineers to become more acquainted with a numerical method which presently is second only to the FEM and which should be expected to gain additional momentum in the next future. Such a course should last three weeks with lecturing only in the morning and with time for studying and solving of simple example problems in the afternoon and the evening.

IV. RESEARCH

A. Organization of scientific and/or technical instruction and guidance

Soon after the expert's arrival in Zhengzhou, a list of topics on which scientific and/or technical instruction and guidance should be provided was presented to him. Table 5 (see next page) contains this list as well as the names of chief counterpart-discussers and the dates of discussions.

In order to guarantee optimal advising, the counterpart discussers were asked to pass written questions to the expert in advance so as to give him some time for preparation. In this context, it should be mentioned that the posed problems cover a number of different fields.

Another reason for suggesting this mode of scientific and/or technical discussions with counterpart staff was the expert's aim to increase the effectiveness of his instruction and guidance by preparing written answers to questions, at least, so long as the severe constraint on time permitted doing this. In view of the language problem, it was felt that providing the discussers with written material would be of great importance. (At the time of preparation of this report, ten out of a total of thirteen discussions with counterpart staff have been completed. Written material was provided for six of them.)

Apart from making it easier for the expert to prepare himself for some of the discussions and to provide counterpart discussers with the mentioned written material, the request to pose key questions

Table 5 - Topics of scientific discussions with counterpart staff

No.	Topic of discussion	Chief counter-part-discusser	Date of discussion
1	Crack-tip analysis for plane strain elasto-plastic problems, based on the FEM	Mrs. Wu Qing-ke	1981-09-24
2	Dynamic analysis of a large structure tester	Mr. Lin De-sheng Mr. Hung	1981-09-26 1981-11-11
3	Set up of data base containing information on (a)mechanical strength and (b) computer programmes primarily based on the FEM	Mr. Shen Yong-min	1981-10-30
4	Solution of elasto-plastic torsional problems of solids of revolution by the BEM	Mr. Chen Zhen-sheng	1981-11-06
5	Elastohydrodynamic lubrication related to engagement of gears	Mr. Wu Xiau-ling	1981-11-10
6	Analysis of bulk temperature of gears and its effect on pinion distortion	Mr. Tang Ding-guo	1981-11-12
7	Some problems on nonlinear analysis for nonmetallic materials	Mr. Zhau Xing-hua	1981-11-13
8	Some problems concerning design of large programmes for structural analysis	Mr. Zhau Xing-hua	1981-11-14
9	Some problems concerning nonlinear analysis with ADINA	Mrs. Xu Fu-di	1981-11-17
10	Present state and tentative future ideas on pre- and post-processors for FE analyses	Mr. Wang Yu-chang	1981-11-18
11	Some programming problems for plane stress analysis using quadratic boundary elements	Mr. Li Hong-bao	1981-11-28
12	Optimal design of two-dimensional shapes by the BEM	Mr. Li Hong-bao	1981-11-30
13	Three-dimensional analysis of mixed mode stress-intensity factors K_I, K_{II} and K_{III}	Mr. Li Hong-bao	1981-12-01

in written has the added advantage of forcing individuals who pose questions to give more thought to these questions. This helps reducing the amount of vague questions.

The described mode for scientific and/or technical instruction and guidance was accepted by counterpart staff. Since the first tests of this mode were successful, no major changes had to be made.

B. Summaries of discussions of research topics

It would be beyond the scope of a Technical Report to give a detailed account of a relatively large number of scientific and/or technical discussions, each one stretching over several hours. Instead of doing this, brief summaries of the discussions of research topics No.1 - No. 10 of table 5, held before completion of this Report, will be given. These summaries will also contain the expert's findings and recommendations concerning the research at ZRIME with which he was confronted. The most important of these findings and recommendations are also listed in the conclusions and the recommendations following the introduction of this Report.

DISCUSSION No. 1 : Crack-tip analysis for plane strain elasto-plastic problems, based on the FEM

Background: A programme for elasto-plastic crack tip analysis was written by the chief counterpart-discusser. The programme is running on ZRIME's TQ-16 computer.

The mechanical background of the numerical analysis is a work by Swedlow (7), characterized by a special crack-tip element of triangular shape. The regular elements are constant strain triangles. Incremental plasticity theory is used. The von Mises yield criterion is applied. The Prandtl-Reuss equations are used as flow-rule.

The finite element analysis features automatic mesh generation and automatic change of mesh for consideration of crack growth.

The programme was applied to a three point bend bar as had been previously analyzed by ten research groups in the USA, all of whom had used the FEM. Wilson and Csias (8) have reported on the results of this round robin test.

Actual discussion: The nucleus of the discussion was the counterpart discussers' concern about large deviations of results as the degree of nonlinearity increases. In the absence of analytical results, the question of reliability of the developed code as well as of the underlying theoretical background arises.

With regards to the employed theory, Swedlow's crack-tip element is based on sound mechanical ground. However, after the advent of the "quarter-point method" a few years ago (9,10,11), there is no longer a need to use elements with built-in crack-tip singularity.

In the absence of an analytical solution there is no other (practical) way of assessing the accuracy of the solution than numerical testing. Suggestions for numerical testing were made. Practical ways of detecting errors were discussed. It was noted that there would be a great chance that elasto-plastic crack analysis would function if (a) elasto-plastic problems without consideration of fracture and (b) elastic crack problems checked out and if parameter studies concerning the gridwork, the incrementation and the equilibrium iterations for elasto-plastic crack analysis demonstrated that the degree of dependence of the numerical results on these factors is within the usual bounds in finite element analysis.

The question which method is the fastest and simplest method for elasto-plastic crack-tip analysis cannot be answered objectively because the analyst's experience plays a great role. It can be said, however, that, at this point in time, the FEM is unquestionably the leading method.

One question referred to blunting of crack tips. It was noted that Swedlow's element does not permit consideration of this effect which Barsoum's quarter-point element (10) does.

The problem of unacceptably slow incremental-iterative analysis was raised. The solution to this problem is efficient coding. For problems in fracture mechanics the inelastic behaviour is usually limited to a region close to the crack front.Outside this region the body is elastic and the incremental stiffness in the elastic part of the body remains constant during the entire computation. This permits developing an efficient solution technique based on "substructuring"(12). In detailed written notes, this technique was explained to counterpart discussers.

There was great concern about the slow speed of the computer at ZRIME. On the longer run it is very problematic to do elasto-plastic fracture analysis on the Institute's TQ 16.

The main findings of this discussion are that (a) slightly outdated finite elements are used, (b) the incremental-iterative nonlinear analysis is inefficient and (c)unrealistic expectations of accuracy are raised. Recommendations for improvement of the present situation involve use of quarter-point elements and of substructuring.

<u>DISCUSSION No. 2</u>: Dynamic analysis of a large structure tester

Background: The tester represents a space frame for which a static analysis has been performed at ZRIME. If the test sample fails suddenly, vibrations of the test device will be induced. Dynamic analysis of the frame will serve the purpose of facilitating the design of the frame including the foundation.

Actual discussion: A relatively large number of problem-related topics were discussed on two non-succeeding half-days. These topics contained (a) possible simplifications of the mechanical model, (b) choice of the forcing function and (c) damping. With regards to (a), simplifications concerning the boundary conditions were suggested for preliminary computer analyses. Concerning (b), several possibilities were discussed. The final conclusion was that the forcing function should consist of a constant part followed by a linearly decreasing part. With respect to damping, a detailed explanation of how to determine the damping matrix $\underset{\sim}{C}$ for transient analysis was given.

Assuming that this matrix decouples the natural modes (so-called Rayleigh damping), the damping matrix can be written as

$$\underset{\sim}{C} = \alpha \underset{\sim}{M} + \beta \underset{\sim}{K}$$

where $\underset{\sim}{M}$ and $\underset{\sim}{K}$ are the mass matrix and the stiffness matrix, respectively, and α and β are constants obtained from tests(13).

In the context of damping, the question of providing discrete dampers was raised. It was noted that the computer programme ADINA permits consideration of such dampers.

The main finding of the discussions is that the present problem is one of practical design which must be approached iteratively. Recommendations for parameter studies were made. These studies would show the sensitivity of the results on various parameters such as, for example, α and β . This would give increased confidence in the reliability of results from dynamic analysis.

DISCUSSION No. 3 : Set up of data base containing information on (a) mechanical strength and (b) computer programmes, primarily based on the FEM

Background: The topic of discussion refers to the previously mentioned assignment to ZRIME to set up the two above cited data bases. The discussion involved several members of the technical leadership of ZRIME.

Actual discussion : When planning such data bases it should first be considered wherefrom to obtain the necessary information for the data bases. Concerning data base (a), national professional societies, such as, for example ASME (American Society of Mechanical Engineers) in the USA or VDI (Verband Deutscher Ingenieure) in the Federal Republic of Germany, should be asked for standards and codes of practice,respectively. They contain information on admissible displacements, strains and stresses and also on ultimate strains and stresses for materials covered by the respective codes. It is recommended to obtain such codes from the following countries: USA, USSR, Great Britain, France, Federal Republic of Germany and Japan. Addresses of professional societies and special agencies concerned with the edition of codes can be obtained via the diplomatic missions of the respective countries in the PRC. A useful source of information is the previously mentioned National Technical Information Service of the U.S. Department of Commerce, Washington, D.C., USA.

It is fair to assume that the period of collecting material will take no less than a year. During this time a group of computer specialists can begin with working out a computerized information-retrieval system at ZRIME. In order to meet the needs of the Research Departments concerned, they all should be engaged in the task of building up a data base on mechanical strength.

Concerning data base (b) the situation is much easier because there is by far less information that needs to be collected. For the purpose of data collection, reference (3) should be of help. It contains a bulk of information on pertinent computer programmes. (Counterpart staff showed great interest in this "file" which the expert had shipped to China).

The main findings of the discussion are that collection of material for voluminous data bases is a time-consuming process which needs to be planned meticulously, and that building up of a data base requires not only technical but also manpower-related considerations. It is recommended that central authorities of the PRC help establishing contacts of ZRIME with the aforementioned foreign sources of information.

DISCUSSION No. 4 : Solution of elasto-plastic torsional problems of solids of revolution by the BEM

Background : The counterpart discusser named in table 5 recently completed an academic thesis on the above mentioned topic. The displacement and stress field resulting from a moment about the axis of revolution was derived with the help of the solution of Kelvin's problem. These fields were then used as fundamental solutions for establishing the boundary integral equation to solve the problems in question. One-dimensional linear boundary elements and bilinear quadrilateral internal elements were used for solving the boundary integral equations numerically.

Actual discussion : Topics of discussion were solution of the axisymmetric problem by the same method and solution of the elastic problem for a general load. The latter problem could be handled by superposition of solutions resulting from individual Fouries harmonics of the given load.

The potential of combining the FEM and the BEM for certain problems was mentioned. The usefulness of the BEM for fracture mechanics was stressed. In this context, an extension of the counterpart discusser's method to problems of fracture mechanics was discussed.

The main finding of this discussion is that the discusser's method represents an attractive alternative to conventional FE formulations. The method is both economic and accurate. It was recommended that the mentioned work be condensed and submitted for publication to the International Journal for Numerical Methods in Engineering. In this context, it is generally recommended that more emphasis be laid on the importance of publishing in foreign scientific journals. Publications in such journals add scientific prestige to ZRIME and, ultimately, to China. Moreover, such publications often lead to scientific contacts with foreign scientists, which should be welcome. The expert sees no unsurmountable problems regarding difficulties with English. ZRIME has a number of researchers who are fluent in the English language. They could be asked to provide help in improving the linguistic style of the manuscripts of their colleagues.

DISCUSSION No. 5 : Elastohydrodynamic lubrication related to engagement of gears

Background: The elasto-hydrodynamic lubrication (e.h.l.) problem for a certain type of worm (Hindley-worm) was previously solved. Convergene of the pressure distribution and the lubrication profile was obtained. Isoparametric finite elements were used. The analyses were carried out at Xi'an University.

Actual discussion: The major part of the discussion referred to a scheme for iterative solution of the thermo-elasto-hydrodynamic lubrication problem which the expert prepared for the counterpart discusser, based on an article by Huebner(14). The mentioned scheme represents an extension of an analogous scheme for the e.h.l. problem. The solution of the thermo-elasto-hydrodynamic lubrication problem must be such that an extended lubrication potential for the fluid, given in (14), as well as the thermo-elastic potential for the solid take on stationary values simultaneously. The temperature distribution in the solid must satisfy the Laplace equation.

Another problem which was discussed was the e.h.l. problem of point contact.

The main findings are that, in principle, solution of the thermo-elasto-hydrodynamic lubrication problem represents a "straight-forward" extension of the e.h.l. problem and that in case of consideration of the temperature-dependence of the viscosity the influence of the sliding velocity on the film thickness in the contact area of gears is insignificant.

<u>DISCUSSION No. 6</u> : Analysis of bulk temperature of gears and its effect on pinion distortion

Background : For high-speed heavy-loaded gears, problems with the contact of meshing occur because of lack of longitudinal (axial) precision. This is the result of the deflection of the pinion under the loading and of the thermal distortion of the pinion as well as of the gear teeth, stemming mainly from the non-uniform distribution of the temperature. A quantitative assessment of the lack of longitudinal precision is important for determination of profile modification and longitudinal correction for high-speed gears, used for compressors and turbo-machines, in order to maintain uniform loading and good lubrication conditions in operation.

Actual discussion : The discussion focussed on a proposal of the counterpart discusser to solve the essentially three-dimensional problem by a semi-analytic, two-dimensional FE procedure making an assumption for the temperature in the longitudinal direction.

A classical, though incorrect, assumption for the temperature in the longitudinal direction is to vary parabolically with an axis of symmetry in the middle of the longitudinal axis. This assumption was made, for example, by Nadir Patir and Cheng (15).

Based on the assumption of a parabolically varying dimensionless temperature parameter ϑ ,given as

$$\vartheta = \frac{k\, p_d\, (T - T_a)}{q_{av}}$$

where k is the thermal conductivity, p_d is the diametral pitch, T is the bulk temperature, T_a is the ambient temperature and q_{av} is the steady-state average heat flux along the tooth length (height), the discusser obtained the following distribution for T:

$$T = \frac{\vartheta q_{av}}{k\,p_d} + T_a$$

Since q_{av} is not symmetric, T will not be symmetric. The discusser's motivation for his proposal was that ϑ could be obtained by the same two-dimensional semi-analytic FE procedure as is described in (15).

The main finding of the discussion is that there is no physical rationale for the proposed approach and no way of "by-passing" the third dimension in either the temperature or the stress problem. It was recommended to use the FE programme ADINA for adequate solutions of both problems.

<u>DISCUSSION No. 7</u> : Some problems on nonlinear analysis for non-metallic materials

Background: The FE programme ADINA permits analysis of certain types of concrete members. This resulted in the interest of counterpart staff in details of such analysis. Several questions were posed, all of which were answered in written.

Actual discussion : Topics which were discussed were (a) various possibilities for constitutive laws of concrete, (b) the mode of consideration of the strain-softening part of the material law for concrete, (c) the role of plasticity theory for analysis of structures made of concrete, (d) the significance of terms such as yield surface and flow rule for such analysis, (e) aggregate interlock and (f) tension stiffening. Moreover, the stress-strain relation for a so-called "Mooney-Rivlin material" (incompressible solid) was discussed.

The main conclusions of this discussion are that usually adequate modelling of the process of fracture of concrete is by far more important than consideration of plasticity in the compression domain and that effects such as aggregate interlock and tension stiffening may be very important. It is recommended that counterpart staff interested in recent concepts on consideration of tension stiffening study two papers by Floegl and the expert (16,17).

DISCUSSION No. 8 : Some problems concerning design of large programmes for structural analysis

Background : Counterpart discussers are engaged in the development of new FE programmes as well as in modification of existing, commercially marketed programmes.

Actual discussion : The question for new developments in the design of large computer programmes for structural analysis was answered as (a) utilization of the data base management system (DBMS) concept and (b) application of free-field data input.

The definition of DBMS, taken from (1) is "a piece of software that is used to manage a data base. A data base is a collection of cross-referenced records stored in a computer's direct-access storage." For large main-frame computers, it is not absolutely necessary to set up a DBMS. For minicomputers, on the other hand, it is of paramount importance that various programme segments interact with the file data base. This is the case, for example, for the SAP-80 programme segments. Each different type of structural member is a completely separate programme (2).

Another important aspect is the free-field input. Wilson (2) lists a number of reasons why he adopted the free-field input concept rather than the interactive input concept. He emphasizes that "... the verification of most of the element data cannot be conveniently accomplished by a plot or graphical display device; whereas, the free-field data file, when displayed, provides a compact summary of a large amount of information."

The main finding of the discussion is that for development of computer programmes for minicomputers efficient programming is extremely important. This implies the use of the DBMS concept. The shorter word length requires multiple-precision software in order to maintain a certain level of accuracy of the analysis.

DISCUSSION No. 9 : Some problems concerning nonlinear analysis with the FE programme ADINA

Background : ZRIME has access to the commercially marketed programme system ADINA. This programme was purchased by FMMBI. The Programme Development Group of the Structural Analysis RD is in the phase of getting accustomed to this programme.

Actual discussion: The main topic of the discussion were methods for solution of simultaneous systems of nonlinear algebraic equations as resulting from geometrically and/or physically nonlinear problems. Special emphasis was laid on the so-called Broyden-Fletcher-Goldfarb-Shanno (BFGS)-method, representing a quasi-Newton method (18), because this method was incorporated into the ADINA programme.

Most of the questions of the counterpart discusser resulted from study of a report on ADINA(19) and of a recent paper by Bathe and Cimento (20) on practical procedures for the solution of nonlinear finite element equations.

Terms such as "slow stiffening" and "sudden stiffening", mentioned in reference (20), were explained. By "slow stiffening" Bathe and Cimento mean a kind of stiffening as is found in geometrically nonlinear analysis of thin plates subject to bending. For "slow stiffening", according to Bathe and Cimento, it is sufficient to reduce the load step to ensure convergence of the Modified Newton—Raphson Iteration. "Sudden stiffening" occurs, for example, for unloading of an elastic-plastic material. For dynamic analysis, convergence of the mentioned iteration scheme will occur if the time step is small enough, but for static analysis the stiffness matrix must be reformed, taking into account that unloading is an elastic process.

This has led to incorporation of a scheme in ADINA, which helps avoiding divergence of the iteration in the case of stiffening ("divergence scheme"). This scheme is based on using the elastic stiffness matrix (to account for "sudden stiffening") and on selection of reduced load increments (to account for "slow stiffening").

The main findings of the discussion are that the nature of the BFGS method is not well understood. This is mainly the consequence of non-availability of recent literature on the fundamentals of this method which is frequently more reliable and economic than are Newton-Raphson Iterations. In order to find out which method is the "best" for a certain problem, it was suggested to implement different methods of equilibrium iterations in newly developed computer programmes.

DISCUSSION No. 10 : Present state and tentative future ideas on pre- and postprocessors for FE analyses

Background : In the process of developing new programmes or modifying existing programmes, based on the FEM, computer routines for facilitating the input of data and checking the correctness of the input were composed at ZRIME. In addition to such preprocessors, also postprocessors were developed. Work accomplished so far includes mesh generation and plotting of the original and the deformed mesh.

The situation in China concerning pre- and postprocessors for FE analysis is characterized by many small-scale efforts for satisfaction of special needs. Counterpart discusser expressed concern over the lack of co-ordination of these efforts which results in incompatibility of software for pre- and postprocessing with marketed multi-purpose FE programmes. Another big problem is lack of hardware for input of data (digitizers, scanners) and for output of data (plotters). Equipment for plotting, for example, is available in Hangzhou. To use this equipment requires more than a night's travel by rail. There seems to be no complete data processing equipment for FE analysis available in China. By "complete" it is meant that in addition to the main-frame computer the aforementioned computer periphery is also available.

Actual discussion: After reviewing work accomplished so far, methods for generation of three-dimensional FE meshes were briefly discussed. Possibilities for use of post-processing in addition to plotting of deformed meshes, principal stresses and iso-stress lines were outlined. Such possibilities are, for example, plotting of load-history and time-history diagrammes and contours of plastic or cracked domains.

Expressing his interest in software for pre- and postprocessing in FE analysis, the discusser was referred to the work of Fredriksson and Mackerly (3) which contains a lot of information on such software in relation to marketed FE programmes. One of the most powerful systems for pre- and postprocessing is GIFTS, developed by Prof. Kamel at the University of Arizona, Tucson, 85721 Arizona, USA. (GIFTS is also mentioned in reference (3)).

The main finding of this discussion is that the great importance of powerful pre- and postprocessing for FE analysis so far did not receive sufficient attention in the engineering community of China. However, there is full awareness among the relatively small number of specialists for the pressing need to make the FEM more attractive via improved pre- and postprocessing. A good deal of the power of FE analysis is lost if this analysis is not accompanied by adequate pre- and postprocessing. Therefore, it is strongly recommended to consider the cost for computer periphery such as digitizers and plotters in any feasibility study concerning purchase of new computers for Research Institutes such as ZRIME.

C. General impression of research at ZRIME

The problems posed to the expert by counterpart staff reflected the variety of scientific tasks assigned to ZRIME. Many of the topics discussed represent relatively high-level, up-to-date research in computational solid mechanics including the FEM and the BEM. In parallel to the international trend in recent years, the volume of work on the BEM should be increased.

The scientific level of most of the counterpart discussers is high. In this context quite naturally the question comes up whether the discussers represent the top segment of researchers/engineers or the broad spectrum of scientific ability. According to senior counterpart staff, the latter is the case.

Many discussions revealed that research in the fields of expertise of the writer would be more effective if the computer situation was better. In the opinion of the writer it will be difficult for ZRIME to maintain or even improve the present level of research in computational solid mechanics on the basis of the present computer hardware, characterized by very small computers and by a lack of computer periphery. This should be a matter of great concern to ZRIME and its superiors.

During the period of scientific and/or technical discussions at ZRIME the expert frequently needed literature. Although he could not find all that he needed, the situation was better than he had expected it to be. With regards to technical journals from approximately 1976 up till now, the situation is much better than for earlier volumes.

Another problem is restriction of scientific output to the "Chinese scientific market" because of language difficulties. The number of foreign-language publications of researchers at ZRIME is very small. This is a pity because it prevents establishing of scientific contacts with foreign colleagues. Noting that a number of engineers and staff at ZRIME is fluent in English, it should present no unsurmountable difficulties to improve the linguistic style of manuscripts.

ANNEX 1

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ANNEX 2

Names and positions of senior counterpart staff with whom the present situation at ZRIME was discussed

Mr. SHEN Yong-min	Vice-director and Chief-engineer
Mr. ZHU Ji-jun	Vice-director and Head of Scientific Research Office
Mr. ZHAO Xing-hua	Deputy-director of Structure Analysis Department
Mr. LI Hong-bao	Group Leader of Programme Development Group of Structure Analysis Dept.
Mr. TANG Ding-guo	Interpreter, ZRIME

ANNEX 3

Check of which of the expert's books, shipped to China, are also available in the Library of ZRIME

* ------- available

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ANNEX 4

Organization of field work

No. of week	from-to	Work Plan
1	9.14.- 9.20.	9.14.: arrival in Zhengzhou; 9.14.-9.18.: discussions with senior counterpart staff, visit of computer center, laboratories and library; 9.19.: set up of work plan
2	9.21.- 9.27.	discussion of research topics posed by researchers and engineers of ZRIME
3	9.28.- 10.4. (10.1-2 holidays)	preparation of English-language lecture notes for participants of a formal course on the FEM
4	10.5.- 10.11.	preparation of English-language lecture notes for participants of a formal course on the FEM
5	10.12.- 10.18.	lecturing (3 hours in the morning, 1½ hours in the afternoon); preparation of English-language lecture notes for a series of special lectures
6	10.19.- 10.25.	lecturing (3 hours in the morning, 1½ hours in the afternoon; no afternoon lecture on 10.24); preparation of English-language lecture notes for a series of special lectures
7	10.26.- 11.1.	10.26.-10.28.: lecturing (3 hours in the morning); 10.26.-10.31.: preparation of English-language lecture notes for scientific conference in Xi'an; 10.30.: discussion of research topic posed by researchers and engineers of ZRIME
8	11.2.- 11.8.	11.2.-11.4.:Xi'an-conference (two lectures on 11.3.; discussion at the University on 11.4.); 11.5.-11.7.: discussion of research topics posed by researchers and engineers of ZRIME
9	11.9.- 11.15.	discussion of research topics posed by researchers and engineers of ZRIME

No. of week	from-to	Work Plan
10	11.16.- 11.22.	11.16.-11.19.:discussion of research topics posed by researchers and engineers of ZRIME; 11.20.-11.22.: preparation of Technical Report for FMMBI
11	11.23.- 11.29.	11.23.-11.25.: preparation of Technical Report for FMMBI; 11.26.-11.28.: discussion of research topics posed by researchers and engineers of ZRIME
12	11.30.- 12.6.	11.30.-12.1.: discussion of research topics posed by researchers and engineers of ZRIME 12.1.: departure for Beijing (Peking)

ANNEX 5

"Weighted" list of contents of original lecture notes on the FEM

"Weights" : A -- less material required for lectures at ZRIME

B -- amount of material just right

C -- additional material required

B 2.3.3 Numerical integration

B 2.3.3.1 One-dimensional (Newton-Cotes, Gauss)

B 2.3.3.2 Two (three)-dimensional quadrature over rectangular (prismatic) domains

B 2.3.3.3 Two (three)-dimensional quadrature over triangular (tetrahedronal) domains (Gauss-Radau, Hammer, Marlowe and Stroud)

3. Axisymmetric Bodies

A 3.1 Axisymmetric loading and torsion

A 3.1.1 Kinematic conditions

A 3.1.2 Finite element of axisymmetric solid body

A 3.1.3 Displacement functions

A 3.1.4 State of strain

A 3.1.5 Element stiffness matrix

A 3.1.6 Determination of element stiffness matrices by the computer

A 3.1.7 General scheme of a computer programme for solutions of problems by means of the Finite Element Method

A 3.1.8 Examples

C 3.2 Axisymmetric bodies under general loading

4. Three-dimensional Problems

A 4.1 Tetrahedronal elements

A 4.1.1 Constant strain tetrahedron

A 4.1.2 Higher order elements

A 4.1.2.1 Quadratic displacements (linear strain tetrahedron)

A 4.1.2.2 Cubic displacements (quadratic strain tetrahedron)

A 4.2 Prismatic elements

A 4.2.1 Elements of first order

8. Nonlinear Elasticity

ANNEX 6

List of contents of special lectures

1. Admissible and inadmissible simplifications of variational methods in Finite Element Analysis

2. Buckling of thin shells subjected to follower-load forces of the form of hydrostatic pressure

3. A warping-function based Finite Element Method for solution of the shear problem for arbitrary anisotropic inhomogeneous cross sections

4. Ultimate load analysis of cracked reinforced-concrete plates, slabs, and shells considering geometric and physical non-linearity

5. Wind-loaded reinforced-concrete hyperbolic cooling towers: Buckling or ultimate load ?

6. Introduction to linear-elastic fracture mechanics by the Finite Element Method

7. Introduction to thermal analysis by the Finite Element Method

8. Constitutive equations for plasticity and creep

9. Introduction to optimum structural design

10. Introduction to fully stressed design