RESEARCH CORPORATION OF THAILAND

APPRAISAL REPORT NO. 17
COMPUTERIZED STRUCTURAL ANALYSIS

BY
JITJAROEN SUNTORNPALIN
PHYSICS AND ENGINEERING GROUP
TECHNOLOGICAL RESEARCH INSTITUTE

ASRCT, BANGKOK 1969
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By Jitjaroen Suntornpalin*

SUMMARY

The worldwide state of the art in the field of computerized structural design is summarized. The superiority of the matrix displacement method, using generalized coordinates, over the force method is discussed. Development of computer softwares for the construction industry is outlined, and the feasibility of establishing a computer software centre within TRI is envisaged.

I. INTRODUCTION

The Classical Theory of Mechanics was originated in Europe in the 18th century. It was rapidly developed during the first half of the 19th century. The theory was concerned mainly with the exact solutions of the complex mathematical expressions based on equilibrium equations, compatibility equations, and boundary conditions of the problem. Due to the narrow fields of its practical application, the second half of the 19th century saw the theory eventually transformed into a new practical form called the Theory of Applied Mechanics. The transformation took place by the injection of some acceptable assumptions into the classical theory; thus certain physical restrictions were relaxed to the extent that practical solutions from specific engineering problems were obtainable by various numerical means. Numerical results obtained from problems in applied mechanics are of course approximate, but suitable for practical uses.

Generally speaking, there are two analytical techniques which are being used at present by practicing engineers in attacking structural engineering problems, viz. the conventional technique and the computerized technique. Though both techniques stemmed from the same stump, the classical theory, their analytical procedures are totally different.

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The main difference is not only in the choice of numerical tools to aid the analysis, but also in the style of mathematical backgrounds used in formulating the related equations.

The computerized technique yields great flexibility in that the computation can be carried out in a well-organized fashion so that a systematic analysis can always be achieved by the aid of a digital computer regardless of the complexity and size of the problems. The human brain is totally replaced by the enduring machine which is capable of doing computation and memorizing things without being fatigued.

Analytical investigation of a structure with several degrees of redundancy always involves a set of linear simultaneous algebraic equations with the number of unknowns equal to the degree of redundancy. To illustrate the complexity of the conventional approach in attacking even an ordinary structural problem, let us consider a set of eight linear equations of this type, where all constant coefficients are non-zero. One would be extremely fortunate if he could obtain the numerical roots of the set by conventional means in one working day, even when equipped with a most advanced desk calculating machine. Without any doubt, the task becomes increasingly laborious and tiresome when the number of unknowns is increased. After a certain limit of, say, twenty unknowns, the solution by any existing conventional approach may be impossible.

This is the regime where most structural engineers resort to a more effective analytical tool, and the digital computer plays the central role in the numerical part. The tool, discovered by an American engineer named Hardy Cross (Cross 1934; Cross and Morgan 1949), is universally known as the moment distribution method. It was in the past very popular among engineers. The other version of this method, developed later by Kani (1967), is even more suitable to be implemented on the computer. However, this method is in fact the limiting case of the more general procedure of Southwell's (1940, 1946) relaxation practice, sometimes referred to as the iteration on finite-difference method, and hence the three names are always interchangeable.

The basic principle of the relaxation practice depends entirely on the technique of finite difference approximation to the differential equations of the idealized problems, based on the idea of Gauss' relaxation process. The practice is considered suitable for the analysis of highly redundant structures such as membrane structures and plates and shells of arbitrary geometry.

Methodologically speaking, the relaxation practice involves systematic iterative operations in transforming, in effect, the fictitious configuration of a structure, due to its initially assigned hypothetical constraints, to an acceptably relaxed state. The result so obtained is regarded as only approximate.

Matrix methods of structural analysis came up to replace the finite difference method because of their greater flexibility together with the general availability of digital computers in the recent past.

A practice calling for the simultaneous use of both techniques, i.e. the matrix methods for formulating the related equations and the iteration technique for the numerical solution of the equations, is currently employed in conjunction with the digital computer by structural engineers. This fashion of analysis helps to reduce the requirement for space in the computer's core storage to a minimum. Nevertheless, all methods involving iterative operation yield productive results in only narrow fields of practical application, and a full utilization of the computer's capability is not always possible.

As mentioned earlier, numerical analysis of redundant structures always involves a set of linear simultaneous equations; solving for the unknown is therefore conveniently achieved by using matrix algebra and a digital computer. But one must not be mistaken in thinking that a complex machine should be used only for solving a set of such linear equations or for performing iterative operations. The computer should be used to substitute for the human brain right from the beginning of the analysis, and it remains under the automatic control of the programme until the desired results are fulfilled. Such a maximum utilization of the computer can only be achieved in structural analysis by applying matrix methods.

The scope of this report is to review the basic idea involved in modern techniques used in structural analysis. The idea is based on a new concept of man-computer relationship.

II. IMPACT OF DIGITAL COMPUTER ON STRUCTURAL ANALYSIS

The most computer-conscious nation in the western world is of course the U.S.A., wherein the computer has become an important tool in various sections of technology. Two important aspects concerning the man-computer relationship have undergone active development since the beginning of the last decade. One is the "hardware" or equipment, and the other is the "software" or the means by which the user and his machine communicate. Apparently, the former had undergone development faster than the latter in the past — a rather unfortunate situation. More recently, due to the vast undertaking in research work leading to the idea of integrated programming system, the latter has begun to gain developing speed, but even now its status is still far below the level of the development of the hardware.

As we in Thailand only use but never produce computers, our direct concern is in the software development.

One of the many important events which took place in the past in connection with software development was the emergence of the "procedure-oriented programming language". This can be considered as the first and most significant forward step in software development whereby the difficulty concerning the man-machine communication has been overcome for the first time. Programming in the machine code has been thenceforth replaced by plain English. Scientists and engineers have been relieved from the hard work of coding, and could devote themselves more fully to creative work. FORTRAN is one of the best known languages in this class.

To match the increasing speed and versatility of the newly developed equipment, the second level of the programming system, called the "problem-oriented language", was subsequently developed. The ALGOL (Stevens 1965) is a language which significantly exemplifies this class. Problem-oriented language has been used extensively in programming special problems where the use of ordinary FORTRAN would be less convenient, although not impossible.

The writer feels that the advent of the problem-oriented programming system was not just an ordinary incident in the normal sense of the computer software term; it was in fact an evolution in the area of man-computer relationship. Its existence has fostered advancement in the structural engineering field tremendously. For this reason a fuller account of this development will be given in Section IV (iii).

It has happened in many advanced countries, particularly the U.S.A., that many similar programmes have been developed by several organizations at approximately the same period. Since a considerable amount of expenditure and effort was needed in developing a serviceable programme, a new idea to save programming isolationism was therefore conceived recently at M.I.T., and a system called ICES (integrated civil engineering system) was eventually set up there. The project has been sponsored jointly by M.I.T., IBM, and a few U.S. governmental agencies. Another similar project which exemplifies this class well, called PLAN (problem language analyser) (Tung and Carsen 1968), is being developed by IBM. Perhaps it is legitimate to name this stage of development the third level.

Unfortunately, our chance of using these systems is very dim, at least for the time being, for they can only be implemented on a machine which costs about $125,000 a year to rent. Obviously, this class of machines belong to the third generation.

Tung and Carsen (1968) have proposed a new approach to avoid the undue overlapping of expenditure due to programming isolationism. They have suggested a sort of cooperative system to pool all branches of engineering software together. They called this system the "universal programme". This is by far the largest undertaking that has ever been attempted in this direction.

We will now turn our attention to our specific topic, the development of man-machine relationship in the area of structural engineering.

Rapidly increasing availability, both in number and choice, of high speed digital computers in recent years has given a great impetus to modern methods of numerical analysis in which the computer plays an important role, and left behind the conventional approaches in which only pencil, paper, and slide rule were normally employed. Structural engineering has not been left out of this innovation.

What we gain from switching to the computerized technique of analysis is threefold:

- firstly, the machine relieves the analyst of the drudgery of tedious computations so that he can devote himself to more creative and fruitful work;

- secondly, the size and complexity of the problem is no longer a formidable obstacle for engineers;

- thirdly, time and expenditure are saved without sacrificing the accuracy of the result.

The most efficient means of employing a high speed digital computer in doing numerical computation is by giving it instructions containing recurring calculations, by which the machine has to obey the instructions in a certain pattern of multiple loops. This procedure coincides with the way in which the operation of matrix equations normally takes place on the computer. Normally, subroutine instructions for matrix computations can be written down by a competent programmer for a digital computer; however, some machine accept what is known in the United Kingdom as the matrix interpretative scheme, such as the BEMAT and SELMA (Argyris and Patton 1967) for instance. This type of matrix code enables the engineer to programme all matrix operations by using only simple instructions; thus the programmer's work load is appreciably reduced, for each matrix notation can be treated in the programme as an operand, a mere single algebraic entity.

Moreover, the complexity of continuous structural systems which are intricately built up demands the use of a computer, not only for the solution of simultaneous equations, but also for the complete process of static and dynamic analysis as well.

Thus one may appreciate by now that, by working in terms of matrix algebra, the analyst is able to formulate matrix equations capable of being programmed in a completely automatic sequence of computer operations, commencing with the basic data and concluding with the desired results.

III. THE COMPUTERIZED TECHNIQUE

It is quite natural that both the iteration and matrix methods possess their own efficiency and shortcoming. A proper choice between the two methods depends almost entirely on the past experience of the analyst, the type of problems, and the type and capacity of the computer available.

Although the finite difference technique is still popular amongst those who use small computers, its scope of practical applications is relatively narrow due to its limited capability in coping with the complexity of the present-day structures. In fact, machines with core capacities of 60 kilobytes or more are not uncommon nowadays. With these machines we do not have to stick to the finite difference technique, since their core capacities are sufficient to accommodate average problems of today using the more sophisticated matrix methods. In the writer's opinion, the finite difference technique has no possible potential to be developed further to the extent that its fields of application can be expanded to cover the whole range of practical problems.

(i) Structural idealization

Theoretically speaking, a continuous structural system should possess an infinite degree of statical or kinematical indeterminacy. One way to find an analytical solution is to devise some means of bringing down the number of redundancies to something finite. The stress and strain distributions calculated on this basis are obviously approximate; the accuracy of the results depends on the degree of idealization imposed on the structure. A good example showing how a structural system is idealized is the standard assignment of ideal pin-jointed property to the semi-rigid joints in frameworks.

When we talk in general about the standard idealization of a structure we must imagine that our structure is covered with a suitable fictitious gridwork, composed of a certain pattern of gridlines, whose intersections are called nodal points. An area enclosed by gridlines is called an element. Stresses and strains within elements and on gridlines are assumed to be functions of geometry. By idealizing our structure in this fashion, the analysis is thus possible using the finite element technique.

It is essential to note that, as far as the numerical process is concerned, any analysis involving iteration process yields only approximate results, whereas the matrix methods, on the other hand, render exact solutions.

(ii) Advantage and disadvantage

Matrix methods	Iteration methods
Advantage:	Disadvantage:
(1) Suitable for any type of structure, simply or complicatedly built up. Difficulty in programming does not arise due to size and complexity of the problem.	(1) Suitable for only a few types of the not-so-complicated structures. Difficulty in programming may increase as the size and complexity of the problem increase.
(2) Suitable for application to both static and dynamic problems.	(2) Suitable for static problems only.
(3) Investigation concerning structural optimization is possible since the analysis always leads to the influence coefficient matrices.	(3) It is impossible to perform structural optimization without paying undue cost for computing time and programming expense.
(4) Structural alteration, modification, and cut-outs can be made to the problem without repeating the calculation right from the beginning, since only a few related matrix elements are affected by such changes.	(4) Structural alteration, modification, and cut-outs cannot be made to the problem without repeating the calculation right from the beginning and, very often, new programmes are needed.
(5) Programmes and arithmetic errors can be checked, and if an error is found, it can be rectified at various stages of computation.	(5) Programmes and arithmetic errors cannot be checked at the intermediate stage of computation.
(6) Every step of the matrix formulation depicts a transparent relationship between mathematical and physical concepts of the structural theory, therefore a consistent programme which enhances systematic computation	(6) Since the theoretical background is lack of relationship between physical and mathematical concepts, it is therefore rather difficult to set up a well-organized analytical course upon which the task of programming

can be produced.

(7) Piecemeal calculation can be achieved by virtue of the matrix algebra; hence a big problem can be computed in part when a one-time computation is not permitted due to the limitation of computing store.

can be based; thus to produce a perfect programme the programmer himself should possess a lot of experience, not only in the area of programming techniques but in the field of numerical analysis as well.

(7) It is not possible to employ piecemeal calculation without undue expenditure; this entails a limitation that only a limited number of unknowns can be computed on a certain computer.

<u>Matrix methods</u>

Disadvantage:

(1) Theoretical backgrounds are contemporary and rather complicated. Optimum results of the analysis can only be attained through the discreet exploitation of the theory by experienced engineers.

(2) For a particular problem, the application of the matrix methods in the analysis always requires a larger core memory than the iteration methods.

<u>Iteration methods</u>

Advantage;

(1) Theoretical backgrounds have been well known to engineers for many decades and are comparatively simple to understand.

(2) For a particular problem, the application of iterative methods in the analysis always requires a smaller core memory than the matrix methods.

IV. THE MATRIX METHODS

(i) General description

The ability to deal with a given structural assembly of arbitrary geometry and complexity by applying the process of structural idealization to subdivide it into a number of substructures of essentially simple component elements is one of the main features of the matrix methods. Inside, as well as on the boundary of each component element, the stress and strain distribution can be adequately defined by a simple assumed form. To ensure the continuity of the assembly, the static equilibrium or kinematic compatibility at mating boundaries between adjacent elements must be maintained throughout the structure. One can expect, consequently, that appreciable complexity in dealing with numerical computations may arise, not only in carrying them out but also in defining them initially. This is the stage in which the strain energy theorem and matrix algebra each play a part. The matrix equations developed in the theory may be regarded as a series of remarkably concise computational instructions, by means of which the final results of the analysis can be formed directly in terms of the basic data. These matrix equations have, moreover, the great virtue that they can be easily interpreted by an electronic digital computer. Thus the special programming of the computer to carry out the computation for a particular problem follows directly from the matrix equations of the analysis.

The simplicity and generality of the matrix language also have enormous advantages from the analytical point of view. They enable us to build up the general theory, following a simple physical argument from the fundamental ideas, with a clarity and generality quite impossible by any other means.

Furthermore, in practical stress analysis, it is not uncommon for the analyst to be faced with problems concerning structural discontinuity, e.g. a cut-out in shell structures of stressed skin aircraft. In such cases the matrix methods are undoubtedly far superior to other methods, if the effects of such discontinuity have to be accounted for in the analysis.

Last but not least, the application of matrices introduces an exceptional conciseness and transparency of mathematics, which is quite impossible with the conventional notation.

(ii) Outline of theoretical development and practical applications

The trend of structural analysis started changing from the conventional longhand methods involving onerous manual computations towards the more sophisticated matrix methods since the advent of the high speed electronic digital computer towards the end of World War II. Aircraft structures at that time had become increasingly complicated. The emergence of the matrix methods of analysis was, in fact, the result of the struggle of a number of aeronautical engineers who, with the notion to expedite their aircraft stressing work and yet maintain an acceptable level of result accuracy, wished to establish a system by which a simplified and systematic analysis of their increasingly complicated aircraft structures could be achieved.

Owing to the methods' beneficial virtue in various aspects, such as simplicity and clarity, combined with compactness and general applicability, they have become, thencefprth, increasingly popular among structural designers in other fields of engineering as well. At present the methods are generally recognized as the most powerful tool in the numerical analysis of engineering structures.

Theoretically speaking, there are two basic principles upon which the formulation of matrix equations are based, viz. "the principle of virtual work or virtual displacement" and "the principle of complementary virtual work or virtual force". The former method deals with kinematic formulation of the related matrix equations in terms of the unknown, actual or virtual displacements, whilst the latter concerns static derivation in terms of the unknown, actual or virtual forces. It is too explicit and irrelevant to the purpose of this appraisal report to give technical details of the two principles. Readers who are particularly interested in these matters should consult Argyris (1954, 1957), Argyris and Kelsey (1956a, 1956b, 1963), for instance.

Much of the early work was contributed by only a few notable authors, such as Argyris (1954,1957), Argyris and Kelsey (1956a, 1956b), Langefors (1951, 1952), Falkenheimer (1953), and Kron (1955). Every one of these contributors, except Argyris, dealt principally with either of the two principles separately. Argyris was the first and only person amongst those few mentioned who dealt simultaneously and explicitly with the two principles in great detail, and, moreover, it was he again who pointed out the duality of the two principles.

Development of the matrix methods may be chronologically grouped into three stages:

(1) In the primary stage, the analysis was limited to only a few

types of aircraft substructural assembly, such as rectangular and tapered spars, box-type wing spars with multirib, closed and open, single and multicell tubes. Computer programming in those days was extremely difficult, for it had to be coded in the machine language (Hunt 1966). Programme development was also costly.

(2) Towards the end of the last decade a radical change took place in the trend of theoretical investigation. The finite element technique had been adopted as a standard analytical practice, whereby all structural problems could be solved. This is the general approach concept. This happening coincided with the emergence of the procedure-oriented language mentioned earlier. Thus new names such as Ferranti's autocode were heard in the U.K. and FORTRAN in the U.S.A. for the first time. Library software had not existed until around 1960 when the computerized technique began to gain enough attention among civil engineers in the U.S.A.

The nucleus of the finite element technique is the influence coefficient matrix of the structural system. This matrix could be formed by using matrix methods. Once an influence coefficient matrix of a structural system is formed, the relationship between forces (or generalized forces) and displacements (or generalized displacements) could be established, and thence the problem can be solved by resorting to either iteration practice or matrix methods.

Success or failure resulting from applying the finite element technique is due mainly to the choice of structural idealized patterns on which the whole process of analysis is initially based. Congruent choices depend solely on the insight and past experience of the analyst. Concerted efforts have been expended, on both sides of the Atlantic, in studying various shapes of elements of varying degrees of complexity. The result of these studies is a fairly rewarding one, for we now have quite an extensive range of elegant idealized elements, each of which has its own special feature, from which they can be selected to fit into our best idealized pattern conforming to the external shape of our specific structure.

One of the foremost contributors of the finite element technique is J.H. Argyris who, with his associates in London and Stuttgart, has laid out a comprehensive computerized procedure for the analysis of highly redundant structures which may occur in any branch of engineering (Argyris 1964, 1966, 1967; Lightfoot and Sawko 1960). The Argyris system of analysis is equally applicable in all domains of mechanical behaviour, i.e. elastic, inelastic and plastic, of materials making up all possible structures. Nevertheless, it should be borne in mind that the Argyris system, though possessing various merits, is basically laid out in the form of conceptual backgrounds, its real practical value depending entirely upon the user's engineering intuitive ability in knowing how to rationalize his specific problems. In other words, if a failure occurs using this system, it is not because of the disservice of the theory but of the user himself for lacking the real insight to cope with his own problems.

(3) A manifold increase in the number of computer users in all branches of engineering, coupled with an increasing availability of the second and third generation machines, gave birth to the integrated programming system. The importance of this system, to the structural engineer, is that it allows him to specify logically the related problems in his programmes in plain English that the computer can understand. ASKA (Argyris and Patton 1967), a system developed by Dr. H. Kamel and his colleague at ISD,* is a good example of this system.

One can view this system from another angle as a very efficient monitor system by which a large number of "job-oriented subsystems" are sequentially brought to their respective locations to assume temporarily their active commands in the computation.

Further details concerning the development in this category is given in the next subsection.

(iii) <u>The integrated programming system</u>

In principle, the shape of the development of structural design is now being moulded to the form of the general design of structures. Included in the concept of general design are the following factors:

- structural loading
- structural geometry
- structural stressing

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- structural optimization
- construction cost.

To incorporate the above efforts simultaneously into the design system will amount to performing the complete analysis of a problem involving systems analysis, which is indeed a vast undertaking involving a great deal of financial and manpower supports.

To depict clearly the extent of the development of the third level programming language that has already occurred as well as its future trend, the writer will present some original words given by notable authors in various fields of engineering. The quotations are extracted from texts of reference (Argyris and Patton 1967) which was presented at the symposium on the impact of digital computers on engineering, held in 1967 at the Royal Aeronautical Society, London.

"Professor J.H. Argyris and Mr. P.C. Patton:

'...Our own software developments are primarily oriented towards the matrix interpretative codes needed to implement our theories...Our current project in this field is the new code, ARGMAT, language for processing data manifolds or any complex branched data structures that may arise in engineering analysis...The features required for this language are:

(1) That it be able to handle large supermatrices efficiently.
(2) That it has dynamic storage allocation over a hierarchy of stores.
(3) That it be easy to programme and check out a new programme.
(4) That it be not only easy to write but also easy to read, so that an existing programme be intelligible and documented by its own text.
(5) ...ARGMAT, namely generalized ALGOL, is so generalized that it is translated to an intermediate language which is still more general than FORTRAN...

'...The trend in computer applications nowadays is towards so-called applications language, ...developed by Dr. H. Kamel and his Applied Programming Group at the Stuttgart Institute. Such languages allow virtual automation of production, planning, and analysis procedures, but they still require some human effort for modelling, data preparation, linear idealization, co-ordinate determination, etc. Such application packages will improve in at least two major areas in the next five to ten years. First they will have to allow communication with the engineer or designer in his own language, the language of graphics. Second, this very facility will require that more sophisticated methods of analysis be embodied in the subroutines of the package itself. For example, a designer should be able to have an instantaneous stress or dynamical analysis of any three-dimensional object or integrated assembly of objects he can draw on a light pen display console...'

"Dr. H. Kamel (discussion):

'The heart of the integrated system...is a language designed to help the engineer to describe his problem to the computer...the first programmer's manual describing our system, ASKA, was issued by our Institute.* Our system also is based on dividing the complex structure into a number of substructures which we call "net"...

While we are pleased with our language as a description one, I am well aware of the amount of development that must still take place before a really integrated system evolves which will also incorporate facilities at the disposal of the aerodynamicist, aeroelastician, draughtsman and production engineer.

Our system, ASKA, is not merely a collection of subroutines; it has an interpreter which accepts statements written in a new artificial language easily understandable by an engineer with a logical mind. Structural engineers with little knowledge of computers and even, in an extreme case, unfamiliar with the Displacement Method, have solved problems using ASKA...' ".

V. A SURVEY OF EXISTING SOFTWARE

A complete list of world's existing software in the area of civil engineering is published regularly in the "International Computer Programs Quarterly". This publication is intended to make known to the public the availability of programmes for all models of computers and to serve as a communication between those who have programmes and those who need them.

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Unfortunately, the writer still has had no opportunity to see a copy of this publication, but has already made a request to TNDC for a sample copy acquisition.

The following presentation is totally based on the very limited information acquired from available technical literature found in the TNDC library and the writer's personal collection.

It is rather profitless to enumerate here the programme titles and published information which had been come across by the writer, since our primary interest is merely collective in the broad aspects of software development and engineering applications.

It has been observed in current practice that two types of software are always mentioned. One is the sectional type, exemplified by a multitude of programmes for calculating stiffness matrices of idealized elements. To form a serviceable programme, several sectional programmes have to be joined together by suitable interspersed passages written by the user himself. The second type is the ready-made or self-contained programme which normally requires only specific data when being used.

In advanced countries most organizations keep their technology and software to themselves, and they never make them available to others commercially. To the writer's knowledge, only one software has been published in a technical report. Anyone who cares to use it can do so free of charge. This software belongs to the Building Research Institute, Roorkee, India. (See Goyal and Sharma (1964) for further details.)

The writer has already tried to dig deeply into what they are doing in advanced countries in the fields of computerized analysis, and could reach as far as the published information and programme titles and no further. This was one of several factors which slowed down the development of the general approach technique, for a lot of manpower, time, and expense had been expended in duplicating similar programmes in the past. What we need now is a joint effort to avoid such unfortunate circumstance.

VI. OUR PARTICULAR PROBLEM

Several digital computing machines now installed within various premises in Bangkok are quite suitable and also available for structural analysis use.

The IBM 360/40 at the National Statistical Office has core storage of 64 kbytes and the 1620 at Chulalongkorn University has 20 kbytes (it probably has been enlarged by now). The Asian Institute of Technology and the Royal Irrigation Department each has one IBM 1130. The 1130 is a very fast machine belonging to the third generation, but it has core capacity of only 8 kbytes.

Generally speaking, the larger the core capacity of the machine, the better it can serve our structural analysing purpose, since our main concern is matrix operation. An ideal machine for structures use must have core capacity of not less than 60 kbytes.

Expansion of computer business in this country is now in progress. Commercial firms have been established recently to provide computer services to the commercial sector. If the great majority of local engineers turn attention to the idea of man-computer partnership and start using computers more in engineering works, better facilities will be available especially for engineering uses in future.

Our objective is a twofold task:

- to expose to the local engineer the idea of man-computer partnership;
- to establish the computer software centre.

Of the two tasks, the former is far more difficult than the latter. While the latter concerns ourselves only and is supported by our own organization, the former needs a full response from the construction sector as well as the educator who is responsible for planning the engineering educational system of the country.

Success of our effort will depend on two basic factors: environment and good planning. Discussion concerning these two matters will follow immediately.

(i) <u>Environment</u>

Thailand is a developing nation. A developing nation requires three major resources: material, manpower, and finance. Our main concern here is manpower. We all are well aware of our shortage of technical people, particularly engineers. This shortage can, of course, hamper the progress of our development tremendously.

Establishing a computer software centre is one of the many ways to compensate for the acute shortage of local engineers working in the field of engineering construction. The major function of the centre will be to foster the use of the computer as a normal tool in structural design work, field work, and construction management by developing general-purpose softwares and making them available to all who want to use them and, on the other hand, to act as the co-ordinating body between different parties concerned who want to share the same area of technological interest.

We have learned from the past that the U.S.A., for instance, had wasted a vast amount of resources by having failed to set up in time some sort of co-ordinating body to centralize the effort in the development of their computer software into one composite organization. We have also learned from them that they had realized just recently their great loss; otherwise they would not be too enthusiastic now about laying out big projects focussing on the area of integrated programming systems. NASA is now busy organizing the effort to lay out a standard code for the analysis of arbitrary structures. Our nation is a poor one. We therefore could not afford to waste our resources in the same manner as the U.S.A. has done in the past. For this reason, we must establish a computer software centre to function as the centre of research work in this field of technology.

(ii) <u>Project planning</u>

The writer has been convinced by previous study of software development in advanced countries that, if we want to develop a project along the lines of an integrated programming system, we must make it a permanent one; otherwise we would not gain anything at all. India, our neighbouring country, has been successful in establishing a permanent computer software centre, of the kind we are proposing, many years ago at the Central Building Research Institute, Roorke. According to an annual report of the Institute, they have quite a few programmes now and are doing well in serving their local requirements. One factor that has furthered their progress has been that they have had quite a few top-grade research workers participating in the project. To mention just one, Professor G.S. Ramaswamy, the present Deputy Director of CBRI, is an excellent scientist with foresight who is leading the group.

Our future success in carrying out our task will depend completely on the response of professional people working in two separate fields: the structural engineer, and the educator who has direct responsibility for planning the future system of our engineering education. Our services rendered to the former group may last indefinitely if we receive enthusiastic response from the group.

Engineering students in advanced countries nowadays are taught to get used to the digital computer as much as they can, even at the undergraduate level. Being familiar with the computer, those students react naturally towards the machine as their close colleague. After graduation those who go to industry, whether working in teams or individually, find that the machine remains their indispensable tool which they must resort to whenever they face numerical problems.

The writer feels that if we want to inject the same discipline into our engineering students, the educator must initiate the move.

At M.I.T. the subject of structural mechanics is being taught to engineering students at undergraduate level in two parts. To teach intuition, theoretical backgrounds are duly emphasized in the first academic phase. Teaching in the second academic phase concerns mainly practical applications, in which matrix methods of structural analysis with numerical application on computers are duly injected. In the writer's opinion, this computer-based method of training is ideal. It should be adopted in Thailand as soon as possible.

Dissemination of technical papers and organizing seminars will also help to foster traditional development along the line of computerization. The idea of doing these is included in our master plan.

Our master plan incorporates two major projects:

- the pilot project, and

- the main project.

The pilot project will be mainly the development of at least two computer programmes laid out to test the public response and reactions towards our idea.

Tentatively, we plan to produce two or three ready-made programmes which are commonly used among structural engineers. The first six months of our pilot project will be spent in developing two self-contained programmes, one of which will be for the analysis of typical rigid and semi-rigid jointed multistoreyed frames where their members cross each other at right angles; the second programme will be for the same sort of frameworks but the members of which cross each other at arbitrary angles. If time permits, a more advanced programme may be investigated taking into account the effect of shear-wall and floor stiffness.

It is expected that these programmes may receive further development during the second six-month period of our proposed two-year pilot project. They should be developed in such a way that a systematic procedure for structural optimization investigations will be naturally incorporated in the previous programmes.

Having progressed that far in the first twelve-month period, we will continue thenceforth to investigate deeper into the possibility of developing detail design systems to be incorporated in the previous programmes. Thus the effort in this phase will be to produce automated design of constituent members of the structural problems subjected to axial as well as flexural loads, detail design of footing, foundation, etc. It is anticipated that this phase will last about six months.

The final phase of our two-year pilot project will be spent in observing and evaluating the public response to our effort. Mathematical statistics and operational research may be employed in evaluating the result as well as in laying out the main project.

The above plan is based on the capability of one research worker alone doing the whole work on the half-time basis. If a staff is formed in future, then the plan has to be revised accordingly.

Planning for the main project could not be revealed now for lack of supporting information, and we have to wait until the pilot project is nearly finished. However, a tentative outline of the policy can be laid out as follows:

(1) Investigation will be oriented along the concept of integrated programming system.

(2) System analysis will be used wherever possible.

(3) The Matrix Displacement Method will be used mainly in this project.

(4) Structural optimization will comply with the method of structural synthesis.

It is expected that in developing our programmes the IBM 360/40 at NSO will be used until the computer unit is established within our own organization as planned. Previous contact revealed that the utilization will be free of charge provided that our authority sends a formal request to NSO prior to the commencing of utilization.

(iii) <u>Technological cooperation</u>

It is important that, if our purpose is a complete success, we then have to maintain some sort of contact with the other similar organizations in order to share their advanced technological knowledge. Since our task in this undertaking is a unique one in the country, it is therefore obviously impossible for us to obtain any technological cooperation (other than computer technology) from inside the country. This circumstance leaves us no other choice than to seek it from abroad. But the writer would like to make it clear that what we need in this context is not foreign aid in the normal sense that a developing country needs from a more advanced one. Our expected cooperation ranges from the low level of acquisition and mutual exchange of technical data, information, etc.; through the medium level of technological consultation and exchanging views on each other's progress as well as comparing the result of works to the top level of possible participation in joint discussions, seminars, symposia, and conferences on related subjects.

At least the first two levels of contact must be maintained all the time between our group and the other friendly organizations concerned abroad in order to avoid isolationism.

Incidentally, there are at the moment at least two groups of research workers, led by Professor J.H. Argyris, working separately in London and Stuttgart, with whom formal contact can be made immediately after this project has been approved by the Board. These two groups are highly specialized in the matrix displacement method in particular. Previous personal contacts revealed that they were extremely fraternal and cooperative.

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