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The Automation of Detailed Drawings by the Lucid System

L'automatisation de dessins de détails à l'aide du système Lucid

Automatisierung von Detailzeichnungen nach dem Lucid-Verfahren

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1. INTRODUCTION

Although engineers have used computers since the mid-fifties to assist them to design structures, it was only in the early sixties that they began to consider the possibility of using them to produce detailed drawings. As time progressed more and more firms began to explore this possibility and by 1965 there were probably about ten firms in Great Britain beginning to develop their own automated systems. From 1964-1969 the author was Chief Structural Development Engineer of a firm developing one of these systems and quite naturally during that period he concentrated solely on his own company's requirements. Similarly persons in other firms developing automated systems were primarily concerned with their own requirements, and no doubt each firm thought that its own method was the best solution. This is a perfectly normal human reaction in which a person's loyalty is to his own employer, and it results in a competitive situation which is highly desirable in the pioneering days of any enterprise, but which also has its disadvantages.

In January 1970 however the author took up his present appointment and was then able to review the problem of the automation of structural engineering drawings on a wider scale than had been possible when employed by an individual company. Consequently in conjunction with Professor G.C. Brock, Head of the Department of Civil Engineering, it was decided to study the problems of automating the production of construction information,and to assess what contribution the Department could make to the needs of the country as a whole. As the study progressed it soon became apparent, that if methods of automating the production of detailed drawings and bar bending schedules were left entirely to individual firms, then the following undesirable features would result:

a) The limitation of capital, and the dispersion of the available specialists in this area of work would probably mean that no system developed by an individual firm would reach its full potential

b) Since no individual firm has sufficient repetition of certain types of work to make it economic to develop automated techniques for these items, then the methods would be restricted only to the most commonly occurring structural elements.

c) Contractors would have to continually educate their staff to understand and interpret the many differing methods of presenting construction information which were being developed. This proliferation of different systems would be particularly unfortunate since it was only in 1968 that a Standard Method of Detailing was recommended[1].

d) Due to the high development cost of this type of work many of the smaller firms would not be able to afford this cost and consequently would not benefit from these new techniques

e) Although not true of all methods, some methods of automation would be such that the cost of interpreting the information on site would increase, and in some cases would also cause more construction materials to be used, resulting in a higher total cost to the client.

It also became apparent that many of these undesirable features could be eliminated, if a large proportion of our construction industry would combine to work together to produce an agreed system. Such a method could, of course only be produced provided there was co-operation from members of the industry almost on a national scale. Thus, although the need for co-operation seemed clear, the method whereby it might be achieved, and whether there was sufficient interest, had yet to be established.

2. PROPOSED METHOD OF CO-OPERATION

During the early part of 1970, discussions on this subject continued and a plan whereby the suggested co-operation might be achieved began to take shape. If the method of automation which was developed was to include a wide variety of structural elements such as bases, pile-caps, columns, beams, slabs, walls, staircases, retaining walls, culverts and subways, it was estimated that the cost of developing and introducing such a scheme might be of the order of £200,000. If this work was to be carried out by a full-time staff, and even if a hundred firms could be persuaded to join in the venture, this would still mean a contribution of £2,000 per member and it was concluded that many small firms would not be able to afford this expense. This method also had the disadvantage that the members would perhaps not feel directly responsible for the development of the system with the consequence that the sense of involvement and mutual co-operation would be lost. It therefore became more and more apparent that the most likely chance of success was to involve the eventual users in creating the system right from the outset, and to make the actual financial contribution from users as small as possible. This could be achieved if the organisation only had a small full-time staff, provided that members themselves would give expert assistance from their staff to develop the system as the need arose. On this basis it was calculated that the subscription rate per member firm could be reduced to only £100 per annum, provided sufficient firms would join in the venture.

It was therefore proposed to adopt the latter scheme and to examine the possibility of forming an organisation jointly between Loughborough University of Technology and members of the Construction Industry to develop techniques to reduce the cost of producing and interpreting construction information. The process of producing construction information would probably be based on the use of standard drawings of various structural components, in conjunction with printed information which, if desired, could be produced by a computer. It was from the initial letters of this process Loughborough University Computerised Information and Drawings that the organisation derived its name LUCID. It was estimated that the work could probably be accomplished in about three years.

The proposed organisational structure of LUCID was that the full-time staff would be directed by the author who would be responsible to a Steering Committee comprised of contributing members. This committee would be assisted by a Technical Advisory Committee, and Working Parties would be formed from the members to carry out and report on specific aspects of the organisation's work. The co-ordination of this work would be one of the tasks of the permanent staff who would also be responsible for preparing and disseminating information and ensuring that any feedback from members was brought to the attention of the relevant part of the organisation.

Discussions of these plans at a meeting in July 1970 with representatives from about fifteen firms indicated that the main principles which have been outlined were generally acceptable, and the interest was sufficiently encouraging to proceed further. By October 1970, after further discussion about fifty firms had nominally agreed to support the idea, and it was therefore decided to attempt to implement the plan.

3. LUCID'S DEVELOPMENT PLAN

Although the development of LUCID is a continuous operation nevertheless its proposed activities can be broadly divided into seven main stages. The stages are not of course separate and overlap considerably in time and content but they are in approximate chronological starting order. The broad titles of the stages are now given so that the overall plan can be appreciated, and later each of the early stages will be expanded. The seven stages are as follows:

a) The setting up of the LUCID organisation

b) The creation of standard drawings

c) The introduction of standard drawings into members' offices

d) Feasibility study of the combined use of computers and standard drawings

e) Development of computer programs for use with standard drawings

f) Introduction of computer programs into members' offices

g) Servicing and updating LUCID techniques

The individual stages of the development plan are now discussed in more detail.

4. SETTING UP OF THE LUCID ORGANISATION

The first step in assessing the interest in the industry was to publicise LUCID's existence, and towards the end of October 1970 a small brochure was sent out to a selected number of firms in the construction industry briefly outlining the aims of the organisation and inviting them to join. Since then no further publicity has been sent out and LUCID already has over 100 member firms.

These members represent all types of firm within the construction industry and include government departments, contractors, consultants, city and county authorities, reinforcement suppliers, structural steelwork designers and fabricators, as well as several computer manufacturers. The task of setting up an efficient organisation to co-ordinate the efforts of such a large number of firms is of course extremely important and took a great deal of time, effort and planning, but it would be inappropriate in this paper to go into too many details of this aspect. It is however worth noting that since LUCID sends out a considerable amount of information to its members such as Technical Reports, User Manuals, Bulletins, Newsletters and Questionnaires, it has set up, with assistance from the University, the facilities to prepare and print all its own documents. A typographical designer was also employed to assist in the design of a consistent house-style for the whole range of its documents.

Our two main committees, namely the Steering Committee and Technical Advisory Committee, have both been formed and LUCID is fortunate to have serving on these committees some of the country's most eminent engineers. In addition to this members have been extremely generous in offering the services of many of their senior staff to assist with working parties, and over 200 engineers have offered to serve in this capacity as the need arises.

During the first year the permanent staff has gradually been increased and has included the services of an engineer financed by the University, a second engineer who was engaged in July and a part-time secretary. While the administrative side of LUCID was being organised the technical side was also progressing and this aspect is reported in the next section.

5. THE CREATION OF STANDARD DRAWINGS

In the initial LUCID publicity brochure it was stated that the process of producing construction information would probably be based on the use of standard drawings of various structural components in conjunction with printed information which would, if desired, be produced by computer. This statement was based on the author's knowledge of the economics of the various techniques which have been employed by various organisations, coupled with the desire to develop a method which would not necessarily be completely dependent on the use of computers. Nevertheless the first task undertaken was to review all known methods of automation to see which, if any, could be recommended as the method which should be used by LUCID. As a result of this study the initial assumption remained unaltered, and it is significant that a report (2) produced by a Working Group of the 'Sub-Committee on the Application of Computers in Structural Engineering', which was established by the Department of the Environment, basically reached the same conclusion.

There are however many ways in which standard drawings can be used in conjunction with printed information, with considerably differing end results, and this whole subject was therefore studied in depth. It should be made quite clear at this point that the use of the phrase 'standard drawings' does not mean employing structural members of standard dimensions. Indeed it should be an essential part of the specification of any automated procedure that it shall not place any restriction on an engineer's choice of type of structure or individual member, but that once he has made this decision it should assist him to produce his detailed drawings more cheaply.

The first task therefore which was undertaken was to study the way in which standard drawings would be used so as to be able to set out a specification of their requirements. However before formulating a specification it was necessary to examine the whole range of structural drawings to see which might be included. It was not considered the task of LUCID to standardise structures, and the choice of structure, its layout and structural form must be determined by the designers to best suit their client's requirements, and it is no part of a communication system to influence this choice. Consequently, it was considered unlikely that layout and general arrangement drawings could be standardised and these are best produced by whatever process the designer feels appropriate. It was assumed that these would generally be scale drawings, and at the present time LUCID will not assist in their production process.

It was however concluded that the production of detailed drawings could be automated and it was convenient and effective to subdivide these into the basic elements of which structures are composed. Consequently the items for which it was decided that standard drawings could be produced are the detailed drawings for individual structural elements such as bases, pile-caps, columns, beams, slabs, walls, staircases, retaining walls, culverts or indeed any others which occur frequently. However, drawings even for an individual element are composed of separate diagrams such as plans, elevations and sections and it is therefore these items which are the basic standard details of a particular structural element.

It follows therefore that whatever process of automating the production of detailed drawings is used, the system must have available a series of preconceived pictorial arrangements. For convenience these will be called standard drawings but only the layout is standard not the dimensions, and they should not impose restrictions on an engineer's choice. There is no necessity to restrict in any way the number of preconceived pictures though it would only be sensible and economical to produce those which recur regularly.

Once having stated the area in which standard drawings could be applied a specification of their requirements was set out and this is now summarised:

5.1 Summary of a Recommended Specification for Standard Drawings

5.11 Standard Drawings. Standard drawings should be of individual structural elements and each drawing should include all the relevant plans, elevations, sections and written information relevant to that element on a single sheet.

5.12 Scale. A standard drawing need not be to scale but there should be a sufficient choice of standards available to eliminate any possibility of misinterpretation.

5.13 Size. A standard drawing should generally be A4 size but A3 size is acceptable if slightly modified to allow easy single folding into an A4 folder.

5.14 Reinforcement Details. Where a standard drawing shows reinforcement, the detailing method, positioning, and quantities of bars shown should conform as closely as possible to the equivalent scale drawing that the standard would replace. Starter bars from adjacent elements must be indicated.

5.15 Concrete Dimensions. Concrete outlines and dimensions should be shown to facilitate checking and shutter erection and to compensate for the use of not-to-scale drawings.

5.16 Material. Standard drawings should be produced on translucent material which will readily accept ink, pencil or typewritten additions and should be such that, even after any additions or alterations to the linework, high-quality copies can be obtained from dyeline machines or any other type of copying machine commonly used in design offices.

5.17 Recommended Layout. For preference the finished drawing inclusive of the written information should be basically the same whether the written information is produced manually, by small computer, via a terminal or using a fast line printer. The form of linework and written information should follow the recommended Standard Method of Detailing[1].

5.18 Future Developments. The standards should be devised to allow the use of any equipment which may be manufactured in the reasonably forseeable future. In particular, the technique should be easily adaptable to the use of plotters and visual display tubes when their use becomes economically viable.

5.2 DEVELOPMENT OF A SYSTEM TO SATISFY THE SPECIFICATION

The specification basically requires that the final drawing of an element contains all the relevant plans, elevations and sections while also allowing the written information to be produced by hand, or by a small computer, via a terminal, or on a large computer with a fast line printer. All this information should be on one sheet of paper and an example of the finished quality envisaged is given in Figure 1.

However, although the final drawing is comprised of two distinct but associated parts namely the picture and the textual information it is vital to subdivide the automation process into two stages. The first of these is to find a method of producing the picture and the second how to combine the text with the picture. The reasons for this are numerous but clearly if one can manage to develop a single method of producing the picture which will easily allow a user to change at will his method of producing the text this gives a very flexible system indeed.

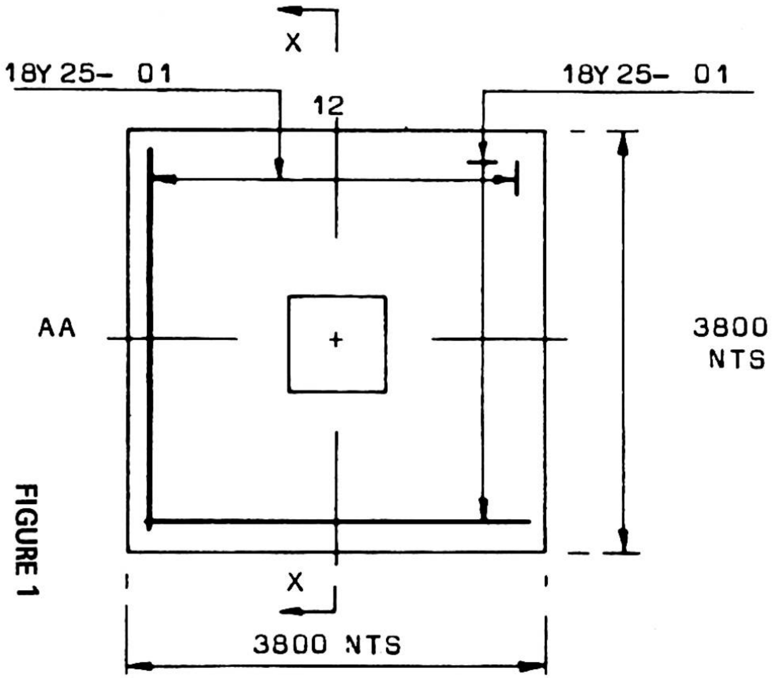
After examining all known systems it was concluded that no existing system in use completely satisfied the specification but that a method known as the 'overlay technique' offered the greatest potential, provided it could be developed to achieve a considerably higher line quality than had previously been obtained, and that it could be coupled with a flexible computer system.

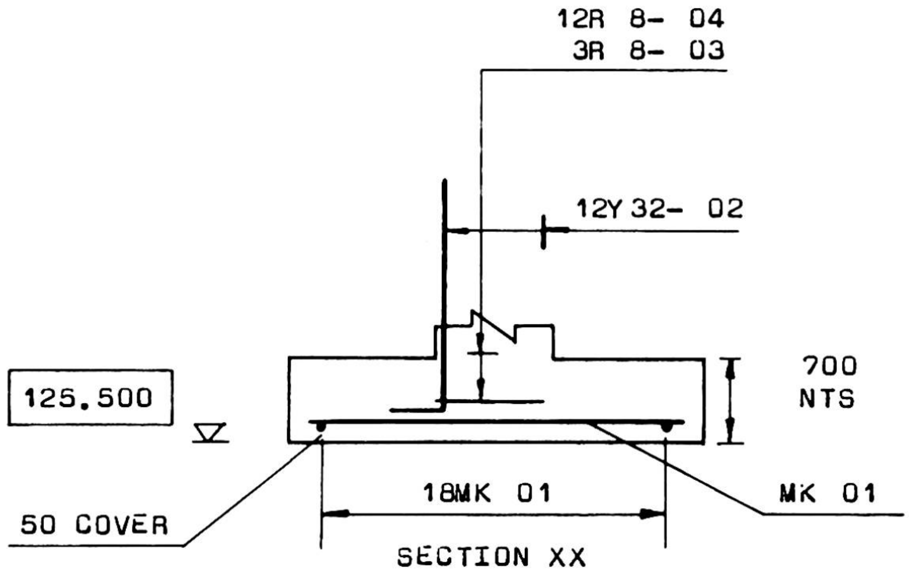
It is perhaps important at this stage to explain briefly what the overlay technique is and why its use was considered necessary. Initially we will only be concerned with the picture part of the drawing and will deal with the text later.

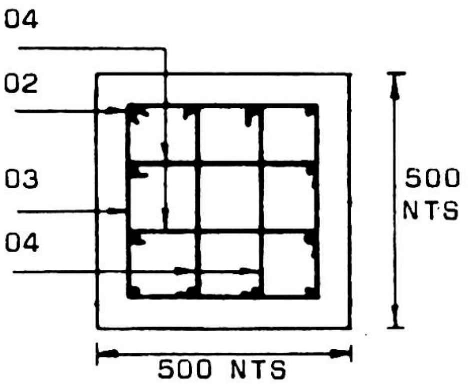
5.21 Method of Producing Linework of Standard Drawings.

One stated requirement of standard drawings was that although they could be not to scale they should not be misleading. For preference therefore every section, plan and elevation should closely resemble its scale equivalent. Suppose therefore that standard drawings are required for all reasonable alternative variations of square and rectangular column bases supporting either square or rectangular columns. From Figure 1 it can be seen that the total drawing comprises three separate details; a plan, a section through the base, and a column section. To ensure that the range of standard drawings will include a close representation of any possible base that may be designed it would be necessary for there to be, say, *four* alternative plans, *three* alternative base sections, and up to *ten* column sections to allow for the commonly used steel arrangements in square or rectangular columns. If all these possible alternative drawings are pre-printed ready for immediate use the number required would be 4 x 3 x 10 = 120. Thus pre-printing complete drawings is impractical and uneconomic, especially for more complex elements. However, returning to the problem of column bases again, instead of pre-printing complete drawings suppose that each of the alternative plans, base sections and column sections were each pre-printed in its correct position onto separate sheets of thin transparent material. In all we would then have 3 + 4 + 10 = 17 separate transparent sheets, each with just one detail on it. When a particular column base configuration is required, the sheet with the most appropriate plan is selected, together with the most appropriate base section and column section. When these three transparent sheets are superimposed we then have the basic linework for the complete drawing. If these three transparent sheets together with a suitable translucent light sensitive material are passed through a dyeline machine and the light sensitive material is developed, we have the required complete drawing on

BASE SECTION 2 COLUMN SECTION 3







ENLARGED COLUMN DETAIL

FIGURE 1

NOTE COVER TO COLUMN STARTER BARS 50

A.N.OTHER AND PARTNERS GREAT GEORGE STREET LONDON S.W.1	
CONGRESS CENTRE RAI EUROPAPLEIN,AMSTERDAM THE NETHERLANDS	
LUCID DEMONSTRATION COLUMN BASE 24 GRID LINES AA-12	
JOB No 30615	DRAWING No 107

one sheet of translucent material. The three transparent sheets of details would then be stored away for further use. Since the complete drawing is made up by 'overlaying' transparent sheets of the individual details of the complete picture it has been named by the author the 'overlay technique'. This paragraph describes the principle of the overlay technique but while the principle is simple, to develop it into an effective working system required a long and tedious research programme.

In the example just described 120 different complete drawings can be made from only 17 overlays, and the attraction of using overlays therefore is that by holding on transparent sheets only the basic individual details of which the total picture is composed, the number of configurations which can be produced is enormous. Any particular combination needed is produced only when it is required and consequently large quantities of pre-printed drawings do not have to be held in stock. The effectiveness of the system becomes even more marked as the number of details on a drawing increases. Thus in the case of beams, if the complete drawing consists of an elevation and three sections (therefore requiring four overlays) merely by having 20 alternative elevations and say 40 different sections then 20 x 40 x 40 x 40 = 1,280,000 alternative beam drawings can be obtained from only 60 basic individual details. While it would be completely uneconomic and unworkable to have 1,280,000 standard pre-printed drawings for beams it is extremely cheap and practical to hold only 60 details.

To operate such a procedure however it is necessary to have a technique whereby it is possible to overlay three or four sheets of details and produce the final composite picture without appreciable loss of quality. It is also necessary to be able to assemble the individual details on the final drawing within close dimensional tolerances both to superimpose individual details, and to ensure a later match with the textual information probably produced by a computer. An additional requirement is that the system must not be expensive to manufacture and the total process must be easy and cheap to operate.

Research into the technique was undertaken both at Loughborough University by Mr. C.A. Yardley and the author, and at the Cement and Concrete Association by Dr. M.R. Hollington. The work was tedious, time consuming and often frustrating but after about six months work the two teams eventually found a suitable transparent material, and a method of printing onto it, and a simple method of maintaining registration between the individual overlays. It may be thought that any transparent material would be suitable but this is not so, since it must be cheap, extremely translucent, durable, not discolour with time, be dimensionally stable in varying humidity and rapidly changing temperature, as well as having a surface which would accept and maintain a printed image.

The overlays which have been produced are on A4 size sheets of transparent material 0.05 mm thick and the relevant details are printed onto this material by a silk-screen printing process. In order to obtain registration between the overlays a thin metal strip with three studs was manufactured and each overlay has three holes punched in the filing margin at the same spacing as the studs. The simple procedure of containing all the sheets within a similarly perforated translucent cover was found to maintain registration and handling through a dyeline machine. To obtain initial correct registration, the back sheet of the cover is fitted on the studs followed in succession by the various overlays and the light sensitive material on which the composite picture is to be produced. Finally the top sheet of the cover is folded over. The package is then lifted from the studs and run through a dyeline machine. Completely satisfactory quality and registration are obtained by this simple and rapid process. It also has the advantage that overlays can be easily assembled by clerical staff and the linework in Figure 1 was produced in less than two minutes using a normal dyeline machine. After use, the overlays are merely filed away until required again. One set of overlays has been used over 1000 times, and they are still in excellent condition.

Quite apart from the fact that the drawing was produced in two minutes compared with about an hour by a draughtsman, the cost of producing the drawing is merely the labour cost of two minutes of a clerk's time plus three pence for a sheet of the highest quality light sensitive paper. The cost of producing this drawing was considerably less than 10% of that when produced by a draughtsman. It should further be noted that this is a very simple drawing, and while the time and cost of producing a drawing by a draughtsman increases with its complexity, the time and cost of producing a drawing by the overlay system is constant and quite irrespective of the complexity of the individual details.

Having found a satisfactory method by which the linework of standard drawings could be achieved, attention was then directed towards combining the picture and text .

5.22 Combination of Pictorial and Written Information

It was envisaged that the textual information could be produced in three basic ways:

a) By hand

b) Using a computer print unit which would allow single sheet feed

c) By a computer print unit using continuous stationery

With method a) there is no difficulty and the linework is produced on a negative which will accept ink or pencil and a draughtsman writes in the appropriate text. When method b) is used again the linework is produced on a negative and this is positioned in the computer print unit, and the computer program is so devised to write up the drawing in the appropriate places. If method c) is used the continuous stationery may be either a diazo or opaque paper. In both cases the text is printed in the required format by a computer onto a plain sheet of paper. If the paper is diazo this sheet is registered with the linework overlays and either a negative or prints can be obtained using a dyleine machine. If the paper is opaque the sheet is registered with the overlays and a copying machine such as a Rank Xerox is used. All these methods have been used successfully to produce drawings which give high quality prints.

5.23 Cost of Producing Overlays

The cost of printing A4 size overlays is less than £0.1 each. Assuming therefore that each different structural element requires an average of 30 overlays then overlays for all the following structural elements; bases, pile-caps, columns, beams, slabs, walls, staircases, retaining walls, culverts and subways can be manufactured for less than £30. Every design office will be issued with sets of overlays and since their use only requires equipment which already exists in a normal design office a cheaper way of producing the linework of drawings is difficult to imagine.

5.24 Advantages of Using Overlays

The main advantages of the overlay system where it is applicable are as follows:

a) Drawings can be produced rapidly, by clerical staff, for less than 10% of those produced by draughtsmen
b) Since the drawings are similar to those produced by draughtsmen, site staff do not require any additional training to interpret the drawings
c) The linework is produced without the necessity of a computer and it is always of a constant and high quality
d) The text may be added by hand, or by the use of a small computer, terminals, or large computers with high speed printers, thereby giving the user considerable flexibility when using the system
e) Since the linework is produced on a translucent material additions and alterations can easily be made by a draughtsman
f) Because the picture can be produced quite separately from the text, and pictures are an *international language*, the system can be used by people of *any nationality* provided the method of detailing is acceptable

The 'overlay technique' has been accepted by the Technical Advisory Committee as the method whereby the LUCID organisation will produce its drawings, and a report[3] describing the extensive development work on it has been issued to members.

5.3 Formation of Working Parties on Standard Details

Once the overall method of producing drawings had been approved, the Technical Advisory Committee began to form working parties to define precisely the concrete outlines and reinforcement details which would be required for each structural element. The first working party to be set up was one on beam-column intersections. Clearly the policy and layout at these positions must be determined before either the beam or column working parties can begin their work. This report has now been prepared and will shortly be sent to the Technical Advisory Committee for their comments. Working parties have also been formed to make recommendations for reinforced concrete bases, pile-caps, staircases, retaining walls, culverts and subways, and to study the problem of detailing structural steelwork. The working parties on columns, beams, slabs and walls will begin their work once the policy on beam-column intersections has been decided.

Once the details of a particular element have been agreed by the Technical Advisory Committee these will be circulated to members for their comments. After any amendment, overlays based on these details will then be produced together with User Manuals, and these will be distributed to selected members for field trials. After a suitable trial period any changes required will be made and the final version of the particular overlays will be produced. This process for various structural elements will probably continue for a period of about a year.

6. INTRODUCTION OF STANDARD DRAWINGS INTO MEMBERS' OFFICES

The exact details of how this will be done will be discussed in great detail with members prior to their introduction. A working party will be set up in the near future to study and make recommendations on both the training programme and method of implementation. The training program will obviously be on a very large scale, and the most appropriate educational methods must be devised, and carefully planned. In addition the method of operation of the techniques in offices, and any organisational changes which may be necessary, will also have to be studied in great detail. To speculate at this stage on what the working party will recommend would be pointless, but the author is conscious that the problem of introducing automated methods into design offices must not be underrated.

7. COMBINED USE OF COMPUTERS AND STANDARD DRAWINGS

Although the computer feasibility study is listed as stage four in the development plan several aspects of it have already been carried out. The first part of this study was whether small computers, terminals and computers with fast line printers could be used successfully with standard drawings. To assist in this exercise a specification of a program related to the design of square column bases was prepared(4). This specification sets out the relevant calculations and flow charts, and includes references to the standard drawings which had been devised for this task. The requirement of the program, starting with the column load, ground pressure and column size as data, was to calculate the necessary base size and thickness, and the base and column reinforcement details, and to print three documents. The first of these documents was the calculations and their answers; the second a schedule listing the bending dimensions of the reinforcing bars in accordance with British Standard 4466(5); and the third was to list the most appropriate combination of overlays to form the picture, and to write up the complete textual information on the picture formed from the listed combination of overlays. Figure 1 is an example of the solution for one particular set of data.

Besides writing programs of our own which were perfectly satisfactory, the specification was also sent out to various manufacturers of small computers, and they were invited to write programs to demonstrate the effectiveness of their machines. Not only has this opportunity been taken up and satisfactorily achieved by seven firms, but three of them have also loaned computers to LUCID as a consequence. The question as to whether computers can be successfully used with standard drawings has therefore already been proved. The second stage of this feasibility study,on which information is already being collected,is to examine the economics of using computers in conjunction with standard drawings. Since our members vary in size from the government's Department of the Environment to small consultants with less than twenty staff then clearly there is no single answer to this problem. We will however endeavour to make recommendations for various sizes of offices so that each member may judge his own position more clearly.

This last item ends the progress that has been made to date,and while it would be premature to anticipate the outcome of the feasibility study,it should be noted that stages given in the development plan allow for its successful outcome and even anticipate that a servicing and updating process will be necessary when the development work is concluded.

8. CONCLUDING REMARKS

LUCID as an organisation is of course still in its infancy but the progress that has been made in less than one year is very encouraging. So far, an extremely cheap method of producing the linework of drawings has been developed and working parties are now formulating the actual details which will make up these drawings. A successful method has also been found to combine the pictorial and textual information whether this is produced by hand or by a variety of computer configurations. As a result of this, the form of drawing produced by this automated method is entirely consistent with the traditional recommended Standard Method of Detailing. Finally and perhaps most important, members of our construction industry have shown, since over one hundred firms have joined together in this venture, that although they are often in competition with each other, this does not preclude them from co-operating on a matter of such national importance.

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SUMMARY

This paper describes how LUCID, an organisation formed by Loughborough University and over 100 firms in the British Construction Industry, has developed a general technique whereby the linework of drawings can be produced for less than 10% of the normal cost. It is shown that text may be added to the linework, by hand or by computer, and that the finished drawing is of the highest quality. The cost and method of operation are discussed and the progress on applying the method to numerous structural elements is reported.