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Optimised computer programs for design of reinforced soil structures

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ABSTRACT: The overall process of engineering design can be considered as a sequence of problem definition, data acquisition, conceptual design and detailed design. The detailed design stage is usually most time consuming, while the initial stages require most use of engineering judgement. Detailed design is time consuming when it requires repetition of straightforward calculations and presentation of the design to a high standard. In both these areas the computer can offer considerable benefits. The authors set out to examine the overall design process for design of reinforced soil walls in the light of considerable experience of engineering design. A computer program was then written which embodied the entire detailed design process from raw data to presentation of the design. The program is highly versatile and interactive.

1. INTRODUCTION

The aim of engineering design is to solve problems. The first stage of engineering design is therefore to define the problem (Fig. 1). This definition may be quite complex; for example, to support a road with a given loading at a certain profile in space, which may be above, at or below existing ground level. Allowing for passage of such things as other roads, paths, pipes, etc., within defined areas. Arriving at a compromise between cost and land take, while satisfying environmental requirements with regard to appearance and noise during construction, in use and during decommissioning. The next stage is to collect the initial data about the problem required for the conceptual design. Omissions in the collection of data could lead to failure to fully solve the problem. In the conceptual design, the engineer decides how to solve the problem in general terms. In the example given above, we might now have cuttings, embankments, bridges, culverts and retaining walls proposed as a means to carry the road along the defined profile. This stage requires considerable engineering judgement and knowledge of what is possible, where, and at what approximate cost. The next stage is to carry out the detailed design; this is likely to require collection of further data to provide parameters for the design methods used. The more precise understanding of a problem which emerges at this stage might well lead to revision of the conceptual design, which may lead back to a requirement for more basic data, and perhaps even to revise the problem to be solved in the light of what is possible. This final stage often requires far less engineering judgement than the initial stages of a design, but can take far longer, due to the tedious nature of many of the calculations involved. The aim of using computers in the design process is to free the engineer's time from carrying out routine calculation. This has two benefits. It allows the distribution in the time spent between the various stages to more closely reflect their importance producing pressure to rush the initial stages. It also allows the conceptual design to be revised with a less severe penalty in terms of time required to repeat the detailed design.

Historically, computer programs have tended to concentrate on one particular aspect of the detailed design calculations, processing data from input files to output files, with little or no user interaction. More recently, attempts have been made to provide "user-friendly" interfaces which provide interactive "front ends" to the programs, and perhaps some sort of graphical output in addition to the data files. The problem usually remains that the method of data entry is cumbersome and difficult to check or change to represent a

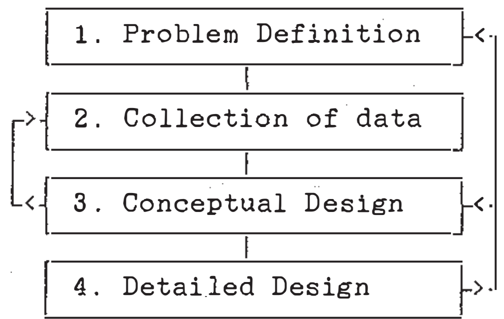
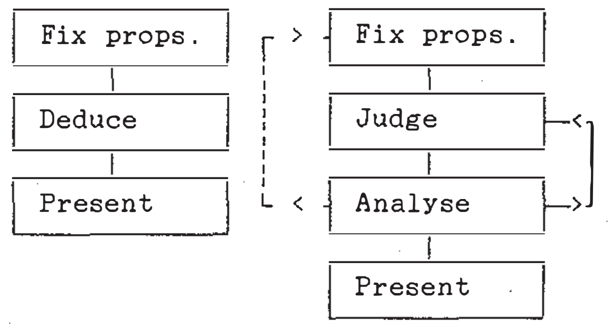


Figure 1 Flow diagram for design process



(a) (b)

Figure 2 Example flow diagrams

different situation, and that the output requires considerable interpretation. Such programs can offer considerable savings in time over hand calculation, but are still far from providing the full potential benefits.

The authors have developed a computer program for the design of reinforced soil retaining walls. The overall design process has been embodied in the program, maximising the benefits of using the computer. The program is written for use on standard micro-computers, which allow the engineer easy and cheap access to powerful facilities for computing, including screen graphics and both graphical and printed paper output. The scope of the program was determined by considering the use which would be made of each feature compared with the time taken to implement it and the time it would save in use.

2. THE PROCESS OF DETAILED DESIGN

In the conceptual design stage the engineer has decided upon how to solve the problem, and will have decided factors such as the required appearance of the solution. In detailed design the engineer decides exactly what must be done, in terms of detailed specification of the nature and location of the solution. The engineer must also communicate this information to whoever must act on it.

There are five different types of process in detailed design:

1. Fix properties of materials
Characteristics of materials affecting the solution of the problem are fixed. This includes deciding upon the particular material to be used out of a range of materials determined in the conceptual design.

2. Deduction
Given one factor, then a parameter in the solution follows directly.

3. Engineering Judgement
Given a set of factors, the engineer estimates parameters in the solution which will be satisfactory - these parameters may be wrong and should be checked by analysis.

4. Analysis
Data relating to the problem, and possibly to a parameter, or parameters in the proposed solution, is processed to give further data. This further data may be a final indication that one aspect of the solution is satisfactory, or may be data needed in a further stage of the design.

5. Presentation
The solution must be presented. This is likely to take the form of drawings and written information giving the assumptions made, the results of the analyses which demonstrate the solution to be satisfactory, and the details of the solution.

Two simple flow diagrams are shown in Figure 2.

Figure 2a shows a design process which is simple deduction - the correct design follows automatically given the problem. A retaining wall design might be reduced to this simple process; however, it is more likely that some engineering judgement is needed to ensure that the design is practical in a given situation. Figure 2(b) shows a design process in which no simple deduction can be made, and the engineer has to propose a complete solution, analyse it, and then make changes to the proposal until the results of the analysis indicate it to be satisfactory. An example might be the design of a slope with a fixed geometry and fixed materials. If the geometry and materials may be varied, then the route shown dotted is added.

Computer programs have commonly been used for the processes of analysis and deduction. Programs for deduction often have the disadvantage that what is deduced does not lead to a practical design; it is often better to leave the decision-making to the engineer. Programs for analysis commonly require the preparation of data files, which may require a lot of work to change if the results are not satisfactory. Typically, the program has to be left, the data file edited, and the program re-run at each stage of re-analysis. If a single analysis needs several runs of the program, for example to find the critical circle in a slope stability analysis, the procedure can become extremely tedious.

With this understanding of the design process, the aim is to make maximum use of the computer in ensuring that the engineer's time is not wasted in carrying out operations which do not need judgement.

3. THE 'TENSAR' REINFORCED SOIL RETAINING WALL DESIGN PROGRAM

The detailed design process for reinforced soil retaining wall design is illustrated in Figure 3. This entire process has been embodied in the Walls program. The engineer begins with the basic requirements and the conceptual design, and ends with all the written information and drawings that are needed. For a straightforward design, the entire process can take as little as five minutes. This would compare with about one hour by hand for an experienced engineer. For a complex design, the process could take fifteen minutes, compared with many hours by hand. As well as the speed of operation, an important feature is the wide range of problems which can be tackled. It was in this area in particular that a balance had to be struck between the time taken to implement a feature in the program and the potential savings in time which would result. At various stages, additional features have been added as it has become apparent that they would get sufficient use to justify the time spent in developing them. These additional features are noted in the description of the program given below.

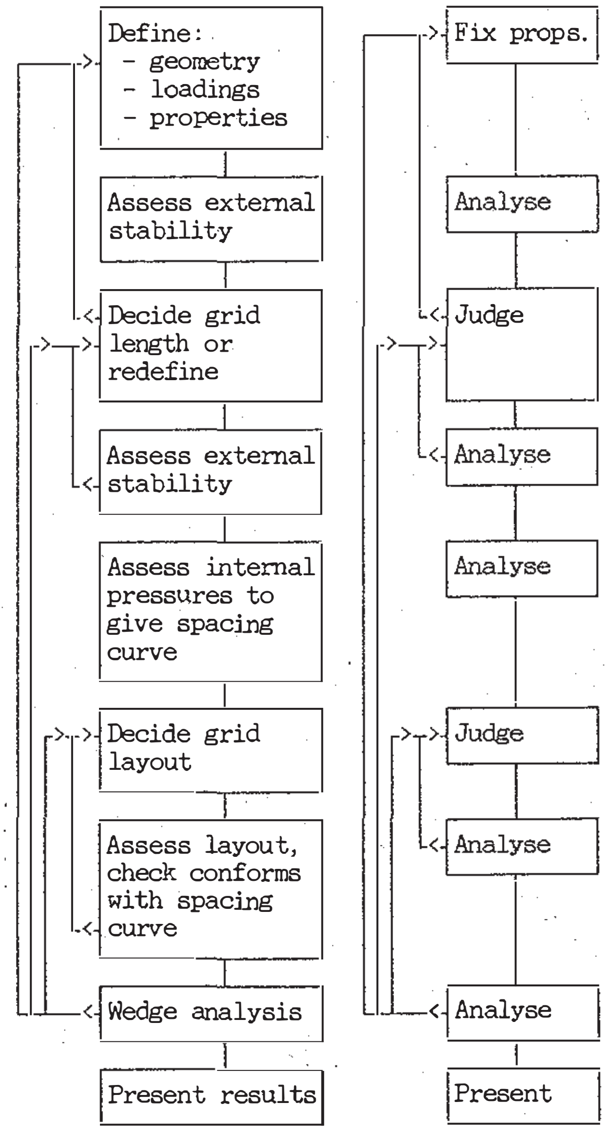


Figure 3. Flow diagram for wall design

It was decided to allow as much freedom as possible to the user in choices of factors of safety and other parameters, while following the tie back-wedge or coherent gravity methods.

The first feature of the retaining wall design process to note is that if the right decision is made every time then each stage is gone through only once. The process is therefore straightforward to embody in a sequential program; the complexity of the order of execution is limited to going back to previous stages in the main sequence. It is simple to impose an additional path immediately before presentation allowing flow to go back to any previous stage. This allows changes to be made in any part of the design. Also, the presentation is given only as an option. This facilitates the use of the program as a tool for preliminary examination of a problem. The main structure of the program is now defined.

The first stage of the program is the definition of the problem. It is in this stage that the scope of the program must be decided. The scope was defined on the basis of the minimum requirements of a reinforced soil retaining wall design program, then by looking at the usefulness of each possible additional feature compared with the time required to implement that feature in the program.

The minimum requirement for the scope of a reinforced soil retaining wall design program is:

1. Vertical wall with identical purely frictional fill in and behind the wall, and no external loads.

The following additional features were considered to be required sufficiently often to justify the time required, which was considerable for item (6):

2. Different properties for the fill behind the reinforced soil.

3. Cohesion in both fills.

4. Surcharge on the top of the wall, starting at the face of the wall, and extending over the backfill.

5. A strip footing at the top of the wall, of any dimensions and at any position on the reinforced soil or the backfill, carrying vertical and horizontal loads, either of which can be zero, the vertical load being at a defined eccentricity.

6. A backfill slope of a defined height at a defined angle, the bottom of the slope being at the top of the wall, and the loadings in (4) and (5) above being on the level ground at the top of the slope.

7. The ability to use more than one reinforcement type in the same wall.

8. Design to the Tie Back-Wedge method, the Coherent Gravity method (French Ministry of Transport 1979), and to the requirements of the U.K. Department of Transport (1987) which incorporates the British Board of Agrément certificate (1986) for Tensar SR2 Geogrids.

At a later date the following additional features were found to be worth the time needed to implement them:

9. Build up of design strength of the reinforcement from characteristic strength and factors of safety.

10. Design to allow horizontal gaps to be left between grids.

Where appropriate, the program was written so that all the features could be combined in a single problem.

A large number of users, or a changing pattern of requirements, may lead to other features being added at a future date.

Another factor to be considered is that the program is needed quickly. It is therefore desirable to plan the writing of

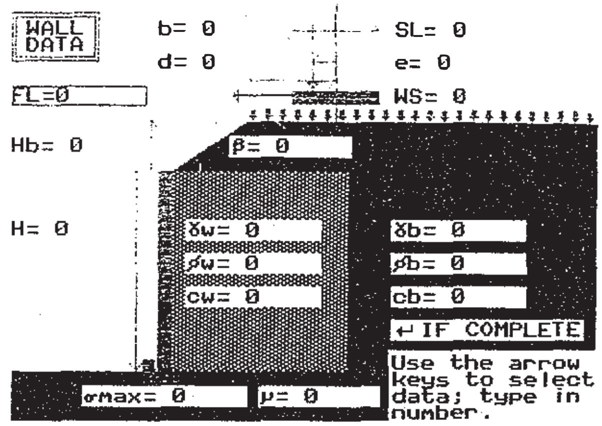


Figure 4. Main data input

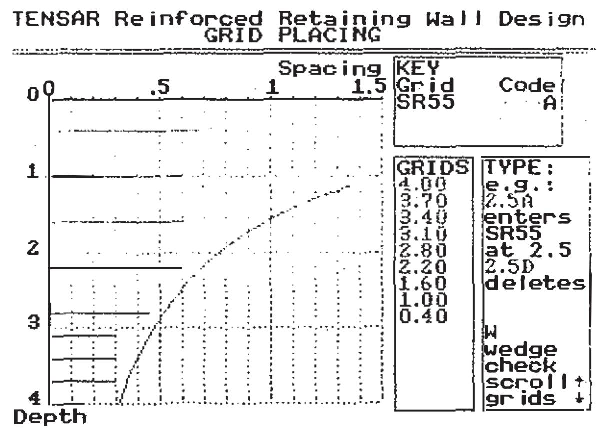


Figure 5. Spacing curve and placing of grids

a program so that it will begin to give benefits as early as possible in its development.

Much of the data is entered into the program on a schematic diagram of a retaining wall on the computer screen. This is illustrated in Figure 4. This clarifies the data being requested, and the sign conventions.

A feature of the flow diagrams in Figure 3 is the absence of any deductive step. Instead, analysis is carried out and the results presented to the engineer for the engineer to make all decisions. The two points where this occurs are in the choice of grid length and in the placing of the grids.

The program analyses the external stability of the wall for a range of grid lengths, and presents the results on the computer screen in the form of graphs of factor of safety versus grid length. The

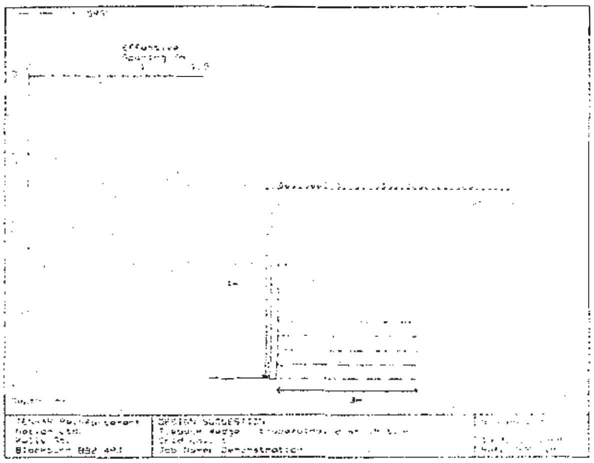


Figure 6. Example plot

engineer can then decide upon a grid length which satisfies the requirements of the particular code to which the design must comply. The program then gives the bearing pressure at the toe corresponding to that grid length, and exact values of the factors of safety against sliding and overturning. The engineer can then use that grid length or enter a new grid length or even go back and change the data.

Next the program analyses the internal stability of the wall using the chosen grid length and presents the results as a spacing curve. An example of the appearance of the computer screen at this stage of the program is given in Figure 5. This gives the engineer all the information needed to choose a practical grid layout; this layout will have the grids placed at levels compatible with the facing being used, while minimising the number of grids without the load in any grid exceeding its safe design load. The layout is then checked by analysing the stability of a number of wedges.

A part of the design process which is often very time consuming is the presentation of the results. As all the relevant information is in the computer at the end of the design, it is possible for the computer to complete the design process by presenting all the input data, the results of the analyses and the final design. This is done using a printer and a plotter. The final design is shown in cross section on the plot, and the grid length and layout is given in the printout, together with the quantities for a unit length of wall. An example of the plot is shown in Figure 6.

4. CONCLUSION

By considering the design process as a whole and looking for every way in which the computer can be used to save the engineer's time and enhance his performance, a computer program has been produced which is optimised for its application.

The resulting design program may be compared with the previous generation of analytical programs which sought simply to take over the repetitive calculations involved in engineering design. The availability of a design program allows the engineer to examine a problem in far more detail in a fraction of the time which used to be needed.

Consideration of the potential benefits of individual features in the program led to a program which began to pay for itself before it was even completed, and in which the time required to write features was carefully balanced against the time which might be saved by having those features available.

The particular program described in this paper has allowed the design department which produced it to handle an unprecedented number of enquiries in the same period in which it was written. Further development of the program continues alongside its use.

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