Research in civil engineering construction and management in South Africa

M F Kaplan

Synopsis
In 1982 the Civil Engineering Advisory Council decided that a study should be made of research in civil engineering construction and management in South Africa. This paper is based on a report to CEAC in this connection. Fifteen potential areas for research and development (R & D) are identified and their priority assessed by Contractors, Consultants, Clients, and Universities and Research Organizations. This is preceded by a survey of the present extent of R & D in civil engineering construction and management in South Africa. The potential for carrying out, and the need to co-ordinate and sponsor R & D in this branch of civil engineering in South Africa has also been investigated. The results of these investigations and the conclusions which may be drawn from them are reported.

Introduction
In its Annual Report for 1978 the Civil Engineering Construction Advisory Council stated that it was generally felt that, other than in the field of roads, research needs in the civil engineering industry in South Africa were not being adequately catered for. During 1979 the name of the Council was changed to Civil Engineering Advisory Council (CEAC) and steps were taken to investigate this matter.

A report was submitted to CEAC in October 1981 in which it was recommended that a Civil Engineering Research Board (CERB) be established for the following purposes:

1. To identify, co-ordinate and monitor research and development (R & D) needs and priorities in civil engineering in South Africa.
2. To promote, encourage, arrange and co-ordinate the carrying out of needed R & D projects in civil engineering.
3. To promote and co-ordinate the collection and dissemination of the results of research and their practical application.

Although the recommendations were accepted in principle, final decisions have not yet been taken concerning their full implementation. It was, however, decided in April 1982 that, as a start, a study be made of research in civil engineering construction and construction management in South Africa. A report on which this paper is based, was submitted to CEAC in February 1983.

It is hoped that in due course studies will also be carried out into other aspects of civil engineering such as structures, geotechnics, transportation, hydraulics, materials and public health.

Objectives
The main objectives of this investigation were:

1. To ascertain the nature and extent of research and development in civil engineering construction, and project and construction management in South Africa.
2. To obtain an indication of the areas of needed research and development and their priority.
3. To assess present and potential resources for R & D in civil engineering construction, and project and construction management.
4. To make recommendations concerning future research and its organization.

Method of investigation
A study was made of recent overseas investigations into the needs for civil engineering research with particular reference to requirements in the field of civil engineering construction, and project management. Research in civil engineering construction was considered not only from a technical point of view but also in regard to other important matters such as economics, productivity, education and training, organization and contractual arrangements.

A memorandum was prepared in which potential areas for research and development (R & D) in this field of civil engineering were indicated. An accompanying questionnaire was also drawn up to assist in obtaining the information mentioned in the section on objectives.

Circulation of memorandum and questionnaire
The memorandum and questionnaire were circulated to:

1. Contractors — organizations primarily carrying out civil engineering construction, although some did design work.
2. Consultants — mainly firms of consulting engineers involved in planning and design work.
3. Clients — primarily the owners or buyers of civil engineering works, e.g. State, Provincial, and Municipal departments, and organizations such as ESCOM and the Anglo American Corporation. Many of these departments and organizations also carried out planning, design and construction.
4. Universities and research organizations — South African universities with departments of civil engineering, building and business administration, and research organizations such as the research institutes of the CSIR, and the Portland Cement Institute.

Copies were also sent, mainly for information, to bodies such as the SA Institution of Civil Engineers, SA Federation of Civil Engineering Contractors, SA Association of Consulting Engineers, SA Association of Municipal Engineers, SA Institute of Steel Construction, SA Road Federation, SA Bitumen and Tar Association, Building Industries Federation of SA, and the Planning Branch of the office of the Prime Minister.

The number circulated in each of the four categories mentioned above is indicated in Table 1. It was not considered necessary or feasible to send the questionnaire to all contractors, consultants, clients etc. The intention was to include a representative number in each of the four categories.

Table 1: Response to memorandum and questionnaire

<table>
<thead>
<tr>
<th>Category</th>
<th>Number Circulated</th>
<th>Number of Replies</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractors</td>
<td>44</td>
<td>25</td>
<td>57</td>
</tr>
<tr>
<td>Consultants</td>
<td>28</td>
<td>19</td>
<td>68</td>
</tr>
<tr>
<td>Clients</td>
<td>24</td>
<td>16</td>
<td>67</td>
</tr>
<tr>
<td>Universities and Research Orgs.</td>
<td>14</td>
<td>8</td>
<td>57</td>
</tr>
<tr>
<td>Total</td>
<td>110</td>
<td>68</td>
<td>62</td>
</tr>
</tbody>
</table>

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Professor M F Kaplan graduated in Civil Engineering at the University of Cape Town in 1942. On completion of military service, he was involved in civil engineering design and construction. Since 1953 he carried out research at the CSIR in South Africa as well as in England and the USA. In 1961 he was invited to become the Director of the Civil Engineering Research Council, now CIRIA, in Britain and was a member of the British Parliamentary & Scientific Committee. He returned to South Africa in 1966 when he was appointed Head of the Department of Civil Engineering at UCT. From 1972 to 1975 he was a member of the Prime Minister's Scientific Advisory Council. After serving as Dean of the Faculty of Engineering he was appointed Deputy Principal and Deputy Vice Chancellor of UCT in 1972. He retired in 1981 and is now an Emeritus Professor in the Dept of Civil Engineering at UCT. He is the author of more than 50 research publications and is Chairman of the Research and Development Committee of the SAICE.
Response to memorandum and questionnaire

The response to the memorandum and questionnaire is indicated in Table 1. It will be seen that 57 per cent of the contractors who were circulated, 86 per cent of the consultants, 67 per cent of the clients and 57 per cent of the universities and research organizations, replied to the questionnaire. Out of the total number of 110 who were circulated, 68 respondents, i.e. 62 per cent replied. Of the 68 replies which were received, 37 per cent were from contractors, 28 per cent from consultants, 23 per cent from clients and 12 per cent from universities and research organizations. The number and distribution of the replies is considered to be satisfactory.

Areas for research and development

In the memorandum which was prepared and circulated the following 15 potential areas for research and development in civil engineering construction and management were indicated (see Appendix A for further details):

1. Resources of the construction industry.
2. Organizational structure and planning of projects.
4. Impact of quality control and assurance.
5. Allocation of risk and liability and the implementation of innovative and new methods in construction.
6. Technology transfer.
7. Impact of governmental regulations concerning health, safety and the environment.
8. Impact of design on construction costs.
10. Education and training.
11. Job environment and labour productivity.
12. Quantification of the effects of factors affecting productivity in construction.
13. Pre-contract preparations
14. Construction equipment and methods
15. Energy consumption.

It must be emphasized that the above are potential areas for research and development and cover broadly based problems in the field of civil engineering construction and management. They are not specific research projects. No reference has been made to construction materials as it is considered that ‘Materials’ is an aspect of civil engineering which should receive separate attention. It is also appreciated that there is no clear dividing line between ‘civil engineering’ construction and ‘building’ construction.

Nature and extent of research in civil engineering construction and management

The purpose of the first three questions in the questionnaire was to obtain an indication of the nature and extent of research and development in this field in South Africa. The response is indicated below.

Contractors

Eighty per cent of the contracting organizations that replied stated that they carried out investigations in one or more of the points mentioned in the section titled Areas for research and development. It will be seen from Table 2 that 70 per cent of the contractors indicated that they were active in the areas of ‘Methods of improving management and control of construction’ and ‘Development of new equipment and construction methods’, whilst 60 per cent were concerned with problems involving ‘Contract documents’. The replies to the questionnaire indicated that the R & D carried out by contractors is done as and when it is necessitated by their own particular requirements, and as part of their every day operations. With the exception of one very large organization, contractors do not have permanent R & D departments.

In a broad sense, research and development is an everyday activity in construction. Contractors are generally known for their ingenuity in developing solutions to specific problems. They modify or develop new equipment and construction methods and they experiment with new applications of existing technology. These important investigations cannot, however, in most cases, be regarded as systematic research programmes aimed at providing general solutions to broadly based industry problems, or at a general improvement in the efficiency and productivity of the construction industry. Innovative procedures or equipment are usually developed in the interest of the organization concerned. One contractor stated that R & D is a ‘logical and natural tool in the hands of private enterprise and should be used in this section of the economy purely for the enhancement and efficiency of the organization which has paid for the R & D.’

In the USA it has been generally assumed that only a fraction of one per cent of the income of the construction industry is invested in research, in contrast with industries such as electronics, which invest an estimated 10 to 20 per cent of income and where research has accounted for leaps forward in technology and productivity. No definite figures are available, but it is most unlikely that more than a fraction of one per cent of the cost of civil engineering work in South Africa is spent on research and development.

It has also been said that the construction industry is almost completely incentive orientated and if therefore there is comparatively little research being carried out by individual construction organizations, it could be because there is little incentive for it. Innovations or new methods in construction research could be protected either by secrecy or patents and they thus disseminate rapidly through the industry.

Thus there is little incentive for one firm to invest heavily in research that can soon be expected to benefit its competitors.

In other cases, the potential market for any one firm is generally too small to justify developing capital-intensive solutions to problems when the investment would have to be written off over several applications. It is therefore not surprising that investment in research by individual organizations in the construction industry is not as great as in many other industries.

Innovative procedures or equipment developed by one construction organization in its own interests may, however, well merit further investigation to determine the boundaries of their application and economy and this necessitates coherent and collaborative R & D effort. There is a need to carry out research which affects the efficiency of the industry as a whole and it is interesting to note that many contractors who replied to the questionnaire indicated that they co-operated and participated in industry-orientated projects.

These included the review and updating of the General Conditions of Contract for civil engineering works being carried out by the South African Federation of Civil Engineering Contractors (SAFCEC) in conjunction with the South African Institution of Civil Engineers (SAICE), the preparation of Standard Specifications for Civil Engineering Construction, productivity studies in conjunction with the National Productivity Institute (NPI), and the work being carried out by the Civil Engineering Industry Training Board (CEITB) in connection with education and training requirements in the civil engineering construction industry.

Consultants

Seventy-four per cent of the consultants who replied indicated that they carried out research in some of the areas mentioned in the section on Areas for research and development.

As will be seen from Table 2, 37 per cent stated that they were involved in investigations associated with contract documents, and quality control and assurance, whilst 26 per cent were concerned with investigations into the impact of design on construction costs.

As in the case of contractors, it is clear that in the main these investigations are concerned with the every day operations of consultants and do not consist of systematic research programmes aimed at broadly based industry problems. One consultant said that at present research was not well organized and related largely to the consulting engineer’s involvement in particular construction projects. Another said that they did not carry out formal R & D as such, but carried out investigations as a general development of particular systems and projects.

Others stated that they did not carry out R & D in the strict sense; what is done is on an ad hoc basis. On the other hand, one consultant said they were involved in the preparation of Standard Specifications for Civil Engineering construction and the revision of the Standard General Conditions of Contract. They were also coordinating various sections of general conditions of contract used by clients. Another organization stated that they were doing research on computer-aided design, and the standardization of engineering information and project procedures. They had a full-time graduate engineer engaged on the development of
Clients

Eighty-three per cent of the clients who replied indicated that they carried out R & D in some of the Areas mentioned.

This category of respondents included state, provincial and municipal departments and organizations such as ESCOM and the Anglo-American Corporation. Most of these organizations are not only clients and owners of civil engineering construction work, but they also do planning, design and construction work.

Reference to Table 2 indicates that they are mainly involved in investigations concerning contract documents, quality control and assurance, and education and training requirements. These investigations are also mainly carried out on an ad hoc basis and are limited to the requirements of the department concerned. The South African Transport Services indicated, for example, that research was carried out to meet their own specific needs, whilst the Cape Provincial Roads Department stated that R & D was limited to the departmental situation.

ESCOM reported that their specifications were being updated and that quality control and assurance procedures were being drawn up. As in the case of contractors and consultants, many clients stated that they cooperated in broadly based construction industry investigations, such as the review of the General Conditions of Contract for civil engineering works and the preparation of Standard Specifications for civil engineering construction.

Universities and research organizations

A limited amount of systematic research in construction and construction management is being carried out at the universities of Pretoria, Witwatersrand and Cape Town. Professor M C Vorster of the Department of Civil Engineering at UCT is carrying out research into the management of construction equipment, education and training requirements, methods of improving management and control of construction, and energy consumption in construction. Professor W F Kilian of the department of building management at UCT is carrying out investigations into the resources of the construction industry, allocation of risk and liability in construction, the effects of the economic environment on the productivity of labour, and quantification of the effects of factors affecting productivity in construction.

Professor F Fourie of the Department of Civil Engineering at the University of Pretoria is doing research on quality control and assurance, allocation of risk and liability in construction, methods of improving management and control of construction, education and training requirements, effects of job environment on productivity in labour, and quantification of the effects of factors affecting productivity in construction. In the Departments of Civil Engineering and Building at the University of the Witwatersrand research is being carried out concerning contract documents, quality control, allocation of risk and liability, management control of construction, education and training, energy consumption, tendering, and corporate financial strategy.

In their Graduate School of Business Administration Research, construction and management covers a wide area but it has been mainly concerned with the development of Project Management Organizations, relative to professional groups such as engineers and architects, industrial relations and human resources, and microprocessor aids, including the construction of microprocessor software for project, cost and resource control.

The National Institute for Transport and Road Research (NITRR) reported that it is doing research in connection with quality control, technology transfer, impact of governmental regulations, impact of design on construction, equipment and construction methods, and energy consumption in construction. The NITRR stated that it would like to move more into the field of management of construction projects.

The National Building Research Institute (NBRI) is doing research in the field of civil engineering concerning organizational structure and planning of projects, contract documents, and impact of design on construction. In the field of building rather than civil engineering construction, it is doing work on management and control of construction, and effects of deficiencies in pre-contract preparations.

The Portland Cement Institute stated that in regard to Quality Control and Assurance it proposed collaborating with the South African Bureau of Standards (SABS) on certain quality assurance issues and that in regard to education and training it is collaborating with the CEITB.

It is clear that the universities and research organizations are carrying out a certain amount of systematic and broadly based research in construction and construction management. Coordination of these activities could, however, be beneficial.

Professional and other organizations

There are a number of other organizations which are involved in research and development activities in civil engineering construction and project management.

In 1978 SAFCEC requested CEAC to consider a uniform approach by the various client bodies in respect of sureties, retentions, maintenance periods and insurance. CEAC accepted an offer by A S Robinson, who was chairman of an SAICE committee dealing with the matter of Standard Specifications, to draw up Standard General Conditions of Contract for civil engineering works which would be acceptable throughout the civil engineering industry. These general conditions of contract which incorporate special conditions of contract for public authorities, have now been endorsed by the CEAC for general use. The City Council of Cape Town collaborated with the SAFCEC in this work. CEAC also accepted that work to further improve the general conditions of contract would continue, as it felt that this greater measure of standardization would result in a reduction in contract disputes.

The SAICE, with the financial support of CEAC, is supervising the preparation of Standard Specifications for Civil Engineering construction and which are being published and issued by the SA Bureau of Standards. This work was financed initially by SAFCEC and the South African Association of Consulting Engineers (SAACE). Ninham Sand Inc were appointed to write the set of specifications and to administer the project. Arrangements have been made to maintain and update these standards on a regular basis through the SAICE Standardization of Specifications Committee and the SABS.

In 1979 CEAC commissioned the Bureau of Economic Research at the University of Stellenbosch, in close cooperation with the Department of Statistics, to compile more realistic indices for use in the contract price adjustment factor.

Also in 1979 CEAC, in liaison with the Building Industry Advisory Council (BIAC), instituted a techno-economic study into the possibilities of creating more job opportunities and increasing the labour intensiveness of the civil engineering, building and related manufacturing industries. A 'Report on the Feasibility of Appropriative Technology in the Civil Engineering Industry in the Development of South Africa' was submitted by NITRR to CEAC in 1981.

CEAC, at the request of SAICE in 1979, gave financial support to a
study undertaken by the Human Sciences Research Council (HSRC) on behalf of SAICE, into the ‘ideal’ ratio between professional engineers and technicians. The purpose was to enable a more realistic assessment of the training needs in the civil engineering industry in view of the manpower shortage in the profession, and in order to assess future requirements.

In 1979 CEAC enquired from SAICE whether it considered design standards being used in civil engineering in South Africa to be appropriate for the current economic situation and whether greater emphasis on cost effectiveness in civil engineering design should not be encouraged. SAICE replied that there was a case for looking at design standards and construction methods and CEAC requested SAICE to formulate an approach to this problem.

SAFCEC reported (Annual Report 1980/81) that a one-day conference organized by BIFSA on productivity in the construction industry was held at which labour, materials, financial, and other aspects were reviewed. An Action Committee, on which SAFCEC was represented, subsequently analysed the matter further from the point of view of labour productivity, and identified areas such as physical environment, training, job motivation, industrial relations and planning. It was stated that a programme had been formulated and that consideration was being given to the establishment of a productivity unit for the building industry.

Because of manpower problems in the civil engineering industry SAFCEC was instrumental in establishing the Civil Engineering Industry Training Board (CEITB) which now operates as a department of the SAFCEC. The main object of the Board is to improve efficiency by training at all levels within the industry and it makes financial grants for the Construction Management Programmes and research projects at the Universities of Pretoria, Witwatersrand and Cape Town. The Board identifies the training needs of the industry, such as the needs of management and supervision, and investigates the training and instructional material required.

The Board also supports research work with grants-in-aid for projects proposed by the construction industry for the benefit of the industry. The CEITB has collaborated with the National Productivity Institute (NPI) in the field of productivity in the industry. The objectives of NPI are to carry out research and provide advice aimed at improving the productivity of the SA economy and elsewhere.

Research into matters of national importance is funded by the SA Government.

In 1979/1980 the NPI undertook fuel conservation studies for the CEITB which revealed the possibility of obtaining substantial savings in the use of fuel in load and haul operations. Subsequently NPI approached SAFCEC in connection with conducting further productivity studies in the construction industry in order to highlight problem areas and to suggest steps to improve the position. SAFCEC agreed that NPI should carry out a feasibility study. In view of the importance of productivity and productivity training, the CEITB reported in 1979/1980 that it had been decided to set up productivity unit for the industry in the NPI to carry out projects on behalf of the civil engineering construction industry through the CEITB, and to also provide a productivity service to individual companies who wish to use it.

In August 1981 the construction productivity unit of NPI submitted to SAFCEC and the CEITB the results of a pilot study on civil engineering construction which was aimed at highlighting areas where NPI could provide services. The study showed that the erratic demand for civil engineering work by the public sector has a detrimental effect on the productivity of contractors, but that companies could still improve their performance within the given constraints. The NPI proposed a series of activities mainly geared to modern management practices and training of skills.

In 1982 NPI was commissioned by CEITB to carry out evaluation studies in a number of areas, eg determine the effectiveness/efficiency of in-company skills and training for construction hands and operators; establish administrative staff effectiveness with a view to computerised systems.

A number of R & D activities, in the interests of the civil engineering construction industry as a whole, are therefore being carried out by, and under the auspices of, a diversity of organizations and it is considered that it would be advantageous if these activities could be coordinated.

Priorities for research

The fourth question in the questionnaire asked respondents to indicate their order of priority for the 15 R & D areas mentioned in this paper. Different respondents gave different orders of priority and the method adopted to obtain an overall assessment was to allocate 15 points to the R & D area indicated as the first priority, 14 points to the second, 13 points to the third, and so on down to one point to the R & D area indicated as being of 15th priority. The average number of points obtained by each of the 15 R & D areas was then ascertained and the areas ranked in the order of the averages. The R & D area with the highest average was accorded the highest ranking.

Ranking of R & D areas

The detailed calculations for the ranking of the 15 R & D areas by Contractors, Consultants, Clients, and Universities and Research Organizations respectively are given in the full report 2 to CEAC. On the basis, however, of all the replies received, the top six R & D areas were:

- Impact of design on construction costs (8)
- Education and training requirements (10)
- Methods of improving management and control of construction (9)
- Contract documents (3)
- Quality control and assurance (4)
- Quantification of the effects of factors affecting productivity in construction (12)

The relative importance of the 15 R & D areas is shown diagrammatically in Fig 1. It will be noted that R & D area No. 7 — impact of governmental regulations — which was ranked lowest, nevertheless obtained 56 per cent of the average points scored by the highest ranked R & D area. This suggests that none of the R & D areas mentioned in the report should be considered to be unimportant and unworthy of attention.

The rankings of the 15 research areas by each of the four categories as well as by the total sample, ie overall, are given in Table 3. The area with the highest ranking overall, viz impact of design on construction costs, was ranked second by contractors, first by consultants, second by clients and fifth by universities and research organizations. This survey therefore indicates that this R & D area merits high priority.

Investigations in this area could, for example, be carried out into such matters as standardization, constructability and flexibility in order to minimize the effects of changes in design, maintenance problems as a result of poor design, interaction between design and utilisation of construction equipment, and optimization of the ratio between on-site and off-site work. From an educational point of view the effects of design on construction costs could be indicated by means of case studies, and the co-operation of designers, contractors and clients should be solicited.

Similarly, each of the R & D areas should be examined, with

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>R &amp; D Area</th>
<th>Percentage of top ranked R &amp; D area</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Resources of construction industry</td>
<td>82</td>
</tr>
<tr>
<td>4.2</td>
<td>Organisational structure &amp; planning</td>
<td>84</td>
</tr>
<tr>
<td>4.3</td>
<td>Contract documents</td>
<td>90</td>
</tr>
<tr>
<td>4.4</td>
<td>Quality control &amp; assurance</td>
<td>89</td>
</tr>
<tr>
<td>4.5</td>
<td>Allocation of risk &amp; liability</td>
<td>76</td>
</tr>
<tr>
<td>4.6</td>
<td>Technology transfer</td>
<td>75</td>
</tr>
<tr>
<td>4.7</td>
<td>Governmental regulations</td>
<td>56</td>
</tr>
<tr>
<td>4.8</td>
<td>Impact of design on construction</td>
<td>100</td>
</tr>
<tr>
<td>4.9</td>
<td>Management and control</td>
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<td>4.10</td>
<td>Education and training</td>
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<tr>
<td>4.11</td>
<td>Job environment</td>
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</tr>
<tr>
<td>4.12</td>
<td>Factors affecting productivity</td>
<td>89</td>
</tr>
<tr>
<td>4.13</td>
<td>Pre-contract preparations</td>
<td>74</td>
</tr>
<tr>
<td>4.14</td>
<td>Equipment &amp; construction methods</td>
<td>29</td>
</tr>
<tr>
<td>4.15</td>
<td>Energy consumption</td>
<td>57</td>
</tr>
</tbody>
</table>

Fig 1: Relative importance of R & D areas according to all categories
particular reference to those with high rankings, so as to identify and define specific research projects which should be embarked upon. The motivation, objectives, cost, proposed work plan, and expected duration of each project should be clearly stated. They should be closely examined and evaluated by those who have knowledge of the problems involved and every effort should then be made to have them carried out.

Potential for carrying out research and development

If research and development is to be carried out, it is necessary to have individuals and organizations with the experience, interest, capability and the resources to do it. Question 6 of the questionnaire, referred to previously, enquired whether 'Your organization or department would be interested in carrying out R & D in any of the areas mentioned'. The response is indicated below.

Contractors

Some contractors indicated that they would be interested in carrying out research. It is however not clear whether they meant that they would be prepared to carry out research projects for the civil engineering construction industry as a whole or whether it would be mainly in their own interest. This needs clarification. One of our largest contracting organizations indicated that it was not interested in carrying out research on behalf of other organizations or groups. Whether this implies that it would not carry out research for the industry as a whole is also not certain. According to Table 4, 20 per cent of the contracting organizations which replied indicated that they were interested in carrying out research in area No. 8 — Impact of design on construction costs — whilst 10 per cent expressed an interest in eight of the other areas, viz. 1, 2, 3, 4, 5, 9, 11 and 14. There was no interest in areas 6, 7, 10, 12, 13 and 15.

Consultants

Reference to Table 4 indicates that the consultants who responded showed a relatively greater interest in the possibility of carrying out research than did contractors. It is however also not certain to what extent their interest was in research for the industry as a whole. Thirty-seven per cent of the consultants indicated an interest in R & D area No. 3 — Contract documents; 32 per cent in R & D area No. 8 — Impact of design on construction costs; and 26 per cent in area No. 4 — Quality control and assurance. These expressions of interest in R & D areas 3, 8

<p>| Table 3: comparison of ranking of R &amp; D areas by different categories |
|--------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Ref.</th>
<th>Area of R &amp; D</th>
<th>Contractors</th>
<th>Consultants</th>
<th>Clients</th>
<th>Universities &amp; Res. Orgns.</th>
<th>All Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Resources of the construction industry</td>
<td>10</td>
<td>4</td>
<td>9</td>
<td>1</td>
<td>8</td>
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<tr>
<td>2</td>
<td>Effects of organizational structure and planning of projects on costs</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Contract documents</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>10</td>
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<td>4</td>
<td>Quality control and assurance</td>
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<td>3</td>
<td>4</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Allocation of risk and liability in construction</td>
<td>7</td>
<td>9</td>
<td>13</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Improvements in technology transfer</td>
<td>11</td>
<td>11</td>
<td>10</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Impact on governmental regulations concerning health, safety and the environment</td>
<td>15</td>
<td>13</td>
<td>15</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>Impact of design on construction costs</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Methods of improvement management and control of construction</td>
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<td>6</td>
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<td>Education and training requirements</td>
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<td>Effects of job environment on productivity of labour</td>
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<td>14</td>
<td>11</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>12</td>
<td>Quantification of the effects of factors affecting productivity in construction</td>
<td>1</td>
<td>10</td>
<td>8</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>Effects of deficiencies in pre-contract preparation on costs</td>
<td>12</td>
<td>7</td>
<td>12</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>14</td>
<td>Development of new equipment and construction methods</td>
<td>2</td>
<td>12</td>
<td>6</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>Energy consumption in construction</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>

<p>| Table 4: percentage of contractors, clients &amp; universities &amp; research organizations interested in carrying out R &amp; D in various areas |
|--------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>No.</th>
<th>Area of Research and Development</th>
<th>Contractors %</th>
<th>Consultants %</th>
<th>Clients %</th>
<th>Universities &amp; Res. Orgns. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Resources of the construction industry</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>Effects of organizational structure and planning of projects on costs</td>
<td>10</td>
<td>5</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Contract documents</td>
<td>10</td>
<td>37</td>
<td>17</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>Quality control and assurance</td>
<td>10</td>
<td>26</td>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>Allocation of risk and liability in construction</td>
<td>10</td>
<td>21</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>Improvements in technology transfer</td>
<td>0</td>
<td>16</td>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>7</td>
<td>Impact of governmental regulations concerning health, safety and the environment</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>8</td>
<td>Impact of design on construction costs</td>
<td>20</td>
<td>32</td>
<td>17</td>
<td>37</td>
</tr>
<tr>
<td>9</td>
<td>Methods of improving management and control of construction</td>
<td>10</td>
<td>11</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>Education and training requirements</td>
<td>0</td>
<td>21</td>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>11</td>
<td>Effects of job environment on productivity of labour</td>
<td>10</td>
<td>5</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>12</td>
<td>Quantification of the effects of factors affecting productivity in construction</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>13</td>
<td>Effects of deficiencies in pre-contract preparation on costs</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>14</td>
<td>Development of new equipment and construction methods</td>
<td>10</td>
<td>11</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>15</td>
<td>Energy consumption in construction</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>37</td>
</tr>
</tbody>
</table>
and 4 coincide very closely with the three top areas which, in the opinion of consultants, require attention.

Clients

Clients, ie State, Provincial and Municipal Departments and organizations such as ESCOM, showed a limited interest in carrying out research. Seventeen per cent indicated interest in research concerning contract documents, impact of design on construction costs, and methods of improving management and control of construction. These research areas also coincide very closely with the areas which according to clients need most attention.

Universities and research organizations

As is to be expected, universities and research organizations showed the greatest interest in carrying out research. Fifty per cent were interested in doing research into Resources of the construction industry, Allocation of risk and liability in construction, and Methods of improving management and control of construction, whilst more than a third (37 per cent) were interested in no less than nine of the 15 areas mentioned, viz 3, 4, 6, 8, 10, 12, 13, 14 and 15. Twenty-five per cent were interested in the remaining three research areas, ie 2, 7 and 11. It thus seems that our universities and the research institutes of the CSIR, are very interested in carrying out research in civil engineering construction, and project and construction management.

Professional and other organizations

As indicated in the sub-section above entitled professional and other organizations, there are other important organizations playing a significant role in research in civil engineering construction and management in South Africa. Reference has been made for example, to the activities of the CEAC, SAICE, SAFCEC, SAACE, CEITB, NPI, HSRC, and the Bureau of Economic Research at Stellenbosch. All of these organizations could play an important part in future research and development in civil engineering construction and management.

Other research areas

Question 5 in the questionnaire asked whether there were any R & D areas in civil engineering construction and management which were not mentioned in the memorandum but which should be considered. The replies did not indicate any significant areas not covered by the 15 R & D areas discussed. This does not mean that there are no other areas for research and development in this branch of civil engineering.

Co-ordination and sponsorship of research

Question 9 in the questionnaire asked ‘Do you consider that arrangements should be made to coordinate, sponsor and monitor R & D in construction and management in South Africa?’ The response is indicated in Table 5. Seventy-two per cent of contractors, 90 per cent of consultants, 75 per cent of clients and 100 per cent of the universities and research organizations which replied indicated that they were firmly in favour of arrangements being made to coordinate, sponsor and monitor research. Sixteen per cent of contractors, five per cent of consultants and 13 per cent of clients did not reply to this question. Four per cent of contractors and six per cent of clients were not in favour. Eighty-one per cent of all replies were in the affirmative, 10 per cent did not give any indication, six per cent were dilatory and only three per cent of the total sample were not in favour.

There can be little doubt that there is a strong body of opinion in favour of the coordination and sponsorship of research and development in civil engineering construction and management.

Table 5: Need to co-ordinate and sponsor research civil engineering construction and management.

<table>
<thead>
<tr>
<th>Category</th>
<th>Yes %</th>
<th>No %</th>
<th>Perhaps %</th>
<th>No Reply %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractors</td>
<td>72</td>
<td>4</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Consultants</td>
<td>90</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Clients</td>
<td>75</td>
<td>6</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>Universities and Research</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Organizations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All categories</td>
<td>81</td>
<td>3</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

Better co-ordination of R & D activities will do much to ensure that the best possible use is made of the limited resources available for research. It will also facilitate the utilisation of the skills and talents of research workers and practising engineers to the best advantage.

In its Annual Report for 1981/82 the National Productivity Institute states that ‘The construction sector, ie civil engineering and building, constitutes one of the major contributions to the economic infrastructure and to the socio-economic scene. The sector ranks first among all sections in the economy in two aspects: employment opportunities and value added. The construction sector is also one of the major contributors to the creation of fixed assets in other industries. The role of civil engineering construction is undoubtedly a major one but, as indicated by the Civil Engineering Construction Advisory Council in 1978, there is a general feeling that research needs in the civil engineering industry in South Africa are not being adequately catered for.

As previously indicated, it can be assumed that in South Africa only a fraction of one per cent of the expenditure on civil engineering work is invested in research. Funds for civil engineering research in general, and not only for civil engineering construction and management, will be required if more research is to be done. The Water Research Commission in South Africa derives its income mainly from rates and charges on water usage and on scheduled irrigation land. Its estimated income for 1982 was almost R5 million. If it is accepted that buyers or owners of civil engineering works should be the main contributors to the cost of research, then one way of obtaining funds would be to add a small percentage of the contract price for civil engineering work to the cost of the contract. If 0.1 per cent were to be decided on, it would mean an additional cost of only R1 000 for every R1 million of construction. On an amount of R2 million, which is the approximate present annual expenditure on civil engineering construction, it would mean a sum of R2 million per annum for research and development.

Summary of conclusions

The following conclusions may be drawn from this investigation:

1. Contractors and consultants, and state, provincial and municipal departments carry out investigations concerning civil engineering construction and management, in the course of their everyday activities. These investigations are generally related to specific construction projects and cannot, in most cases, be regarded as systematic research programmes aimed at providing general solutions to broadly based industry problems, or at a general improvement in the efficiency and productivity of the civil engineering construction industry as a whole.

2. Contractors and consultants, and state, provincial and municipal departments do however participate and collaborate in research activities which are carried out under the auspices of bodies such as the CEAC, SAICE, SAFCEC, SAACE and CEITB in the interests of the industry as a whole.

3. A limited amount of systematic research in civil engineering construction and management is being carried out, in the interests of the industry as a whole, in the departments of civil engineering, building management, and business administration at the Universities of Pretoria, Witwatersrand and Cape Town and at research institutes of the CSIR such as NITRR and NBRRI.

4. A number of R & D activities, in the interests of the civil engineering industry as a whole, are being carried out by, and under the auspices of, a diversity of other organizations. CEAC has, for example, provided financial support for a number of investigations, such as the drawing up of Standard General Conditions of Contract (at the request of SAFCEC); the preparation of Standard Specifications for Civil Engineering construction; the compilation of realistic indices for the contract price adjustment factor by the Bureau of Economic Research at Stellenbosch University; a study of labour intensive construction (in liaison with BIAC) and a study by HSRC into manpower requirements (at the request of SAICE). The CEITB is concerned with education and training whilst the CEITB and SAFCEC have collaborated with the NPI in the carrying out of productivity studies in the field of civil engineering construction.

5. It is considered that there would be considerable merit in co-ordinating all of the above R & D activities.

6. Although no definite figures are available it is considered that in
relation to the size of the civil engineering construction industry the amount of effort being devoted to research and development in the interests of the industry as a whole is not very great. In recent years there has been more R & D activity as a result of the efforts of organizations such as SAFECCEC, SAICE, SAACE and CEAC. Their efforts should be fostered and coordinated.

7. On the basis of all the replies received from contractors, consultants, clients, and universities and research organizations, the research and development areas which should receive greatest attention are:

- Impact of design on construction costs
- Education and training requirements
- Methods of improving management and control of construction
- Contract documents
- Quality control and assurance
- Quantification of the effects of factors affecting productivity in construction

8. There was not an absolute consensus of opinion amongst contractors, consultants, clients, and universities and research organizations on the ranking of the 15 R & D areas mentioned. This is to be expected as different organizations and different individuals place a different emphasis on different problems. Whilst it would be unwise to make rigid deductions, it is felt that the evidence is sufficiently good to provide broad guidelines in regard to priorities.

The top overall priority — Impact of design on construction costs — was, for example, ranked second by contractors, first by consultants, second by clients and fifth by universities and research organizations.

9. The support for all 15 R & D areas mentioned in this report is considered to be such as to indicate that none of these areas can be regarded as being unimportant and unworthy of attention.

10. Contractors, consultants and clients are to a limited extent interested in carrying out research and development in civil engineering construction and management. It is not certain to what extent this interest is in regard to the requirements of the civil engineering construction industry as a whole, and this should be clarified.

11. Universities and existing research organizations, at present, constitute our main resources for the carrying out of research in civil engineering construction and management in the interests of the civil engineering industry as a whole. Wherever possible, the assistance of contractors, consultants and state, provincial and municipal departments should be obtained.

12. Professional bodies and other organizations such as CEAC, SAICE, SAFECCEC, SAACE, CEITB and NPI play, and should continue to play, an important role in research and development in civil engineering construction and management.

13. A very large majority of contractors and consultants; state, provincial and municipal departments; and universities and research organizations are in favour of improved co-ordination and sponsorship of research and development in civil engineering construction and management.

14. There is a need for further research not only in civil engineering construction and management but also in other branches of civil engineering such as structures, geotechnics, materials, hydraulics and public health. Funds for research are required. One way of obtaining funds would be to add a small percentage of the contract price, for civil engineering work, to the cost of the contract. A percentage rate of 0.1% to 1% of every R1 million of construction, could mean a sum of approximately R2 million per annum being made available for research and development.

It is encouraging to report that the Civil Engineering Advisory Council has established a Research Advisory Committee for civil engineering construction and management which will examine and evaluate specific research projects. It is hoped that the necessary funds will then be made available to implement the projects approved by CEAC and that further developments along the lines which have been indicated will in due course take place.

References

Appendix A

Areas for research and development

In the memorandum which was prepared and circulated the following 15 potential areas for research and development in civil engineering construction and project and construction management were indicated:

1. Resources of the construction industry: To make the most effective use of the resources of the civil engineering construction industry studies should be made of the capacity and capability of the industry in South Africa to undertake various types of work. This would enable planning authorities to assess overall and under-capacity for the design and execution of different kinds of civil engineering construction at any particular time. The problems of increasing or decreasing design and construction capacity on an ad hoc basis are considerable and investigations into the resources and capability of the industry in relation to the planning and phasing of future construction could be of great value.

2. Organizational structure and planning of projects: In construction projects a large number of participants are involved such as clients, planners, designers, contractors and sub-contractors, inspectors and suppliers. The relationships and interactions between these participants can be very complex and varied. There are also many different types of construction projects each large, small, industrial and multi-disciplinary. Some of the major problems which affect construction schedules and costs are considered to be due to the nature of the organizational arrangements for carrying out construction projects.

There is a need to study the effects of alternative organizational forms on the cost and time schedules of construction projects with a view to determining the most effective organizational and administrative arrangements for various types of project. Ways and means of improving the quality and promptness of decision making, particularly at the very early stages of planning and design have been stated to be an important area for investigation. Studies could be made of the relationships between, and the responsibilities of, all concerned in various types of contracts, including 'Turn-Key' and management contracts. Improvements in the procedures and systems of communication between clients, designers and contractors, and between the design office and the site could also be investigated.

3. Contract documents: Disputes arising out of the contract documents are rapidly becoming one of the principal features of major construction projects. The reasons for this should be established. Some of the problems emerging from present forms of contracts are the identification and allocation of major contract risks and fair and expeditious handling of contract disputes.

There appears to be a need to develop more satisfactory forms of contract, especially for work that cannot be preplanned fully and for work involving a wide number of subcontractors and sub-contract work. Rational and systematic methods for assessing claims, and the advantages and disadvantages of arbitration and litigation should be investigated.

4. Impact of quality control and assurance: There is a need to establish realistic requirements for the quality of materials and workmanship which are appropriate for various types of work. Investigations are required to ascertain what standards are realistically attainable by 'normal' workmanship and the extent of the controls and supervision required to achieve 'special' standards. Inspections to ensure that the quality of the construction is up to the standard desired often result in stoppages of work. This leads to increased costs because it incurs the expense of idle machinery and manpower and the impediment of the flow of the work. Investigations into the degree of inspection required, and into methods of accomplishing it, should be undertaken. There is also scope for the development of quality control devices which will minimize stoppages of work.

DIE SIVIELE INGENIEUR in Suid-Afrika — September 1984
5. Risk and liability and the implementation of innovative and new methods in construction: The increasing trend towards litigation, and the ever broadening definitions of liability and damages, are not conducive to innovation and the use of new methods and equipment in the construction industry. Investigations are needed to determine what can be done to improve the climate for innovation and the implementation of potential cost-effective new technologies and procedures.

Risk identification and analysis, inherent in various forms of the construction process, e.g. design-build, project management, etc., could be studied with a view to quantifying the potential savings that may be effected by the alternative assessment of risks. In many projects, a small percentage of the tasks to be performed bear most of the risk. Research could suggest ways and means of equitably assigning responsibility and liability for construction risks. This would improve the climate for developing and implementing innovative and inventive technologies in construction.

6. Technology transfer: The indications are that there is inadequate awareness and use of the knowledge presently available, a lack of transfer of experience and good practice from one project to another, and poor documentation and dissemination of innovations that might be of benefit to others. There is a need for studies of engineering, economic and other lessons to be learnt from completed projects. Experience from construction projects should be documented in a form which would enable future planners, designers and contractors to learn from the successes and failures of their predecessors. Due to the lack of consistent and transferable documentation, most of the innovative ideas and planning which have been developed go no further than the immediate applications intended by their originators.

Research should be carried out to determine what kind of clear, concise, factual, transferable and usable documentation would be of most value for recording, preserving and transferring the important lessons being learned on construction projects. Case studies on important features, events, decisions, methods and other worthwhile matters should be carried out with reference to failures and problems to be avoided in the future, as well as to successes.

Computer-aided information systems for the construction industry should be developed to disseminate knowledge of research and development at home and abroad.

7. Impact of Governmental regulations concerning health, safety and the environment: Governmental regulations to minimize the risks posed by construction projects to health, safety and the environment, have important effects on the quality and costs of construction. One of the major problems is to evaluate the effectiveness and efficiency of these regulations, in achieving their desired objectives, against the attendant delays and extra costs to which they give rise.

Those involved in construction must be able to identify and evaluate the impact of these regulations on their decisions. Ways and means of relieving the impacts of the decisions necessitated by these regulations could be investigated.

Ways and means could also be developed of advising the public of the concern of the construction industry in maintaining the environmental standards desired by society.

8. Impact of design on construction costs: Design decisions have a great impact on construction operations and costs. In the conceptual, preliminary, and detail design stages of a project, careful consideration should be given to the influence of design features, material and components on the quality and the costs of construction. Investigations could for example be carried out into such matters as standardization, flexibility in order to minimize the effects of changes, maintenance problems, interaction between design and utilization of construction equipment, optimization of the ratio between on-site and off-site work, and constructibility.

9. Management and control of construction: The cost of a construction project is to a large extent dependent on the efficient and effective utilization of resources on the construction site. Construction managers need to have information available to assist them in selecting from alternative resources and in allocating them efficiently, effectively and economically. Investigations could be carried out to develop computer-aided management information systems which will assist managers and members of the construction team in processing and managing information concerning the construction process.

10. Education and training: The education and training requirements of the construction industry need further investigation. The requirements for suitable career development programmes for potential project managers could for example be studied with particular reference to multi-disciplinary design and construction projects.

11. Job environment and labour productivity: To increase on-site productivity the man-on-the-job must be provided with the physical and psychological resources required to maximize his productivity. The factors which affect productivity, and the quality of workmanship, should be identified e.g. continuity of work, mobility, industrial relations, site amenities, motivation, job satisfaction, health and other factors which affect the quality of life aspects of job productivity. Policies and practices can then be developed to provide the desired on-site production environment.

12. Quantification of the effects of factors affecting productivity in construction: To investigate and improve the productivity of resources in construction it is necessary that research be carried out to quantify the contributions of the various factors in productivity such as capital, labour, technology, materials, organization, management, etc. To be able to estimate the possible cost effects as the result of, for example, better job-site management and control, the use of different materials, the substitution of capital for labour, or technology for labour, requires the collection of data and the construction of models which can quantify the impacts of the above factors. This will facilitate decision making and policy.

13. Pre-contract preparations: Delays in such matters as the obtaining of permits, the relocation of services such as electricity, sewerage, roads, water, etc., can have an important effect on the start-up of construction work and lead to increased costs. Investigations into the development of techniques and practices to be applied in the pre-construction phases to reduce or eliminate delays in construction due to the above factors, are considered to be necessary.

14. Construction equipment and methods: There is much scope for research into the choice and productivity of equipment, and methods for the execution of construction work. The improvement and development of plant and equipment also offers many opportunities, e.g. hydraulic or pneumatic plant for the transport of materials and spoil, better methods of moving, lifting and placing large and heavy units, new methods for ground and fill compaction, and improved methods for excavating trenches, installing pipes and services, backfilling and reinstatement.

15. Energy consumption: The development of methods for the evaluation and rating of energy consumption in the manufacture of the materials used, and in the construction process itself, is needed. This would facilitate materials and system selection during the design process, on an 'energy effective' basis, e.g. which structural system and materials would be the most 'energy effective', concrete beams or steel girders, suspension or cable-stayed bridges? The efficient use of energy on the site could also be investigated.

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