Proc. of the Eighth Intl. Conf. on Advances in Civil, Structural and Mechanical Engineering - CSM 2019

ISBN: 978-1-63248-170-2 DOI : 10.15224/978-1-63248-170-2-19

Paper General Contractors' Support Work and Formwork Practices and Perceptions

John Smallwood

***Abstract*—Reinforced concrete construction entails substantial support work and formwork activities, which expose workers to, inter alia, work at elevated heights, ergonomic hazards, and hazardous chemical substances. Furthermore, support work and formwork are required to support and or restrain substantial loads and forces, is dependent upon a range of resources, and is influenced and contributed to by a range of stakeholders. Consequently, the integration of design and construction, scientific designs, the implementation of documented Quality Management Systems and H&S programmes, and optimum appropriate education and training are essential.**

Certain categories of problems relative to support work and formwork such as damaged components, inadequate design, and inadequate erection are experienced more frequently than others; GCs adopt an informal approach to support work and formwork; in general, recommended support work and formwork interventions can be deemed to be taken between rarely to often / often; although scientific calculations can be deemed to be undertaken, not all support work and formwork designs are scientific; quality management is more informal than formal; contractors' management and supervision contribute more than designers to overall quality assurance; designers do influence support work and formwork; contractors' management and supervision contribute more than designers to design, quality assurance, quality control, and maintenance of support work and formwork; GCs experience support work / formwork and structures' related problems infrequently as opposed to frequently, and support work, concrete, and H&S problems do occur.

Recommendations to realise an improvement in performance include: supervisory training courses; safe work procedures; implementation of documented Quality Management Systems and H&S programmes, and the development of codes of practice.

***Keywords*—construction, health and safety, formwork, support work**

I. Introduction

The report 'Construction Health & Safety Status & Recommendations' highlighted the considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry [1]. The report cited the high-level of non-compliance with H&S legislative requirements, which is indicative of a deficiency of effective management and supervision of H&S on construction sites as well as planning from the inception / conception of projects within the context of project management. The report also cited a lack of sufficiently skilled, experienced, and knowledgeable persons to manage H&S on construction sites.

The spate of collapses in South Africa include the Pretoria North slab collapse, 1996, a notable collapse, which was 'flagged' in the 'Construction Health & Safety Status & Recommendations' report [1]. Then, more recently the Tongaat mall collapse in November 2013 [2] while under construction, highlighted the nature and extent of collapses involving reinforced concrete structures and support work. Furthermore, there have been a plethora of collapses between these two collapses, including the Injaka bridge collapse in July 1998 [3].

The Health & Safety Executive (HSE) [4] states that the causes of many past failures of support work were foreseeable and could have been prevented by proper consideration when planning, erecting, loading, or dismantling the support work.

The Advisory Committee on Falsework [5], which reviewed support work and formwork failures in the United Kingdom, illuminates the issues relative to support work in the introduction to their report. The constraints set by the need to temporarily support construction works in exactly the right position are severe. Each project is unique. There is considerable doubt about the actual loads that will occur. The need to dismantle support work after use introduces further problems. Hazards arise from the prevailing weather, unexpected site conditions, and from the non-availability of critical resources such as material. A further complication is the involvement of different contributors in the various processes. The design of the permanent works is invariably undertaken by consulting engineers, and the design of the support work by contractors. Support work components may be supplied by suppliers, supplemented by contractors, and be erected and dismantled by specialist subcontractors. Alternatively, specialist subcontractors may supply, erect, and dismantle support work. Such diverse contributions introduce difficulties of communication and a confusion of responsibilities, sometimes exacerbated by complicated contractual arrangements.

Given the documented impact of accidents, the influence of H&S on other project parameters, the need for a multi-stakeholder approach to H&S, and the number of slab, support work, and other collapses in South Africa in recent years, a study 'support work and formwork practices' was conducted. The objectives of the study were to determine the:

- Importance of the project parameters;
- Frequency of support work / formwork related problems;
- Frequency of support work / formwork interventions;
- Basis of design of support work and formwork;
- Activities conducted / interventions used to ensure that support work / formwork conforms to requirements;
- Extent to which contributors contribute to the overall quality management of support work / formwork;

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- Frequency at which organisations experience support work / formwork and structures' related problems, and
- Potential of various interventions to result in an improvement of support work / formwork practices.

II. Review of the Literature

A. *Support work and formwork failures*

The causes of support work and formwork failures are classified as enabling, triggering, and procedural [6]. Enabling causes are defined as events that contribute to the deficiencies in the design and construction of the support work, and include inadequate: design; soil foundation; cross-bracing, and design / construction of permanent structure. Triggering causes are events that initiate support work collapses, which are mostly and essentially the result of excessive loads exerted during construction. The loads are usually not expected, or underestimated at the design stage, and hence they trigger a local failure, which propagates a major collapse. Examples include: fierce winds; impact loads during concreting; vibration from equipment, and improper / premature removal of support work components. Procedural causes are procedural in nature and do not directly cause the support work to fail. However, the procedural errors are often hidden events that produce the enabling and trigger events. Furthermore, they are not easily extracted from failure reports due to a variety of reasons: inadequate review of support work design / construction; lack of inspection of support work during concreting, and inadequate communication between parties involved.

An investigation of falsework in the United Kingdom [7] concluded, inter alia: at all levels there is a lack of understanding of the fundamentals of stability of falsework and the basic principles involved; wind loading is rarely considered; contractors and specialist contractors predominately believe that the drawings and schemes prepared by proprietary suppliers are 'designed' and that they have incorporated in the 'design' all the correct assumptions necessary; there is a lack of checking of falsework designs prior to use, whether by suppliers, contractors or specialists, is seen to be an industry-wide problem, and there is a lack of falsework design experience in contracting, as the 'design' process has moved to suppliers.

B. *Realising safe support work*

The Advisory Committee on Falsework [5] presented a range of technical recommendations, recommended procedures, and education and training recommendations. The categories of technical recommendations include: estimation of loads; identifiable horizontal forces; 3% horizontal load rule; lateral stability; bracing and lacing; longitudinal stability; selection of materials and equipment; proprietary equipment; tolerances; factors of safety, and research and development. The categories of recommended procedures include: choice of parties; the design brief; acceptance of falsework drawings; loading of falsework; general site procedures; a Temporary Works Coordinator; summary, and responsibility and liability. Education and training recommendations include: professional training; course standards; CITB facilities; certification; incentives; time scale; financial arrangements; trade unions; need for a textbook of falsework technology, and summary.

The HSE [4] refers to planning, design, materials, erection, loading, striking and dismantling, and training. Planning – all concerned should contribute towards the preparation of a design brief, which should serve as the starting point for subsequent decisions, design work, calculations, and drawings. Initial planning should address what needs to be supported, how it should be done, and how long the support work will be required. Design – all support work should be designed, which varies from the use of simple tables and graphs, to site-specific design and supporting drawings. Particular attention should be given to: stability requirements, lateral restraint and wind uplift on untied decking components; designing such that support work can be erected, inspected, and dismantled safely; selecting adequate foundations or providing information to ensure adequate foundations are used, and providing the information that the temporary works coordinator will need to manage the interface between the permanent structure and the support work safely. Materials – should be strong enough for and stable in use; damaged components should not be used, and different proprietary components should not be mixed. Erection – before erection begins, a risk assessment should be conducted, and safe work procedures and a method statement indicating how all the hazards will be managed should be developed. Support work should be stable at all stages of erection and should be regularly checked. Erectors should know: where to commence; whether the equipment supplied is the same as that ordered; the stages when checks and / or permits are required; and whether checks and permits have already been conducted and issued respectively. Loading - upon completion, all support work should be inspected and certified as ready for use. A written permit-to-load procedure is strongly recommended. The frequency of subsequent inspections will depend on the nature of the support work, but should enable any faults to be rectified promptly. Striking and dismantling – a sequence for dismantling should be determined and detailed; the temporary works coordinator should sanction the time of striking for each section of the support work, and the safety of workers from falling objects should be assured. Training – temporary works coordinators, supervisors and workers that erect, strike, and dismantle support work should be competent and trained in the H&S of support work.

C. *Contributions to an improvement in support work and formwork*

Many of the recommendations made by the Advisory Committee on Falsework [5] will contribute to an improvement in support work and formwork. These include the following: the design of all support work regardless of scale; research relative to the actual loads experienced relative to support work; optimum communication between designers

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and others on and off site; inclusion of training in safe work procedures (SWPs) in support work and formwork technology and practice; instruction in the special features of support work in civil engineering and architecture education; the requirement of the design of support work to be included with the design of the permanent works as evidence of professional competence; the provision of short courses in support work for engineers and architects; training in support work for operatives and first line supervisors, the assessment of their performance and certification thereof; the development of a support work handbook and data sheets, and the development of a support work textbook.

III. Research

The study sample stratum consisted of all 453 general contractor members of a national employer association, which are based in three metropolitan areas, namely Cape Town, Durban, and Johannesburg, which were surveyed using a questionnaire.

19 Surveys were returned to sender (RTS) due to addressee cessation of business activities, or change of address. 35 Responses were included in the analysis of the data, which equates to a net response rate of 8.1%.

The majority of contractors undertook industrial (68.6%) and commercial (68.6%), followed by domestic (40.0%) work, and only 5.7% undertook infrastructure work.

25.7% of the contractors undertook double storey, 37.1% undertook between 0–10 floor, and 2.9% 0-20 floor construction work. Therefore, approximately 66% of GCs would have managed the erection and dismantling of support work and formwork.

Table 1 indicates the mean number of production workers employed per category. 94.4% of skilled workers, 81.9% of semi-skilled, and 58.3% of general workers were employed on a permanent basis.

TABLE I. MEAN NUMBER OF PERMANENT AND TEMPORARY PRODUCTION WORKERS EMPLOYED.

Category	Response (%)		
	Perm	*Temp*	*Total*
Skilled	86.4	5.1	91.5
Semi-skilled	62.0	13.7	75.7
General	101.2	72.4	173.6
Total	249.6	91.2	340.8

Table 2 indicates the importance of five project parameters to respondents' orgnisations in terms of a mean score (MS) ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (not important) to 5 (very important). It is notable that the MSs are all above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the parameters as important to their organisation. However, it is notable that the top three ranked project parameters, including H&S, have MSs > 4.20 ≤ 5.00, which indicates the parameters are between more than important to very / very important. Given that schedule is one of the three traditional project parameters it is notable it's MS is 0.46 lower than the MS of H&S. Given that the MSs relative to schedule and the environment are > 3.40 ≤ 4.20, they can be deemed to be important to more than / more than important.

TABLE 2. IMPORTANCE OF PROJECT PARAMETERS TO RESPONDENTS' ORGANISATIONS.

Parameter	MS	Rank
Quality	4.76	1
Productivity	4.67	2
H&S	4.58	3
Schedule	4.12	4
The environment	3.59	5

Table 3 indicates the frequency at which support work / formwork related problems occur in terms of percentage responses relative to a frequency range 'never' to 'often', and a MS between 1.00 and 4.00. The problems with MSs > 2.50 can be deemed to generally occur. Damaged components predominate, followed by inadequate bracing. Although no problems have MSs > 3.25 ≤ 4.0, which indicates a frequency of between sometimes to often / often, the first four ranked problems have MSs > 2.50 ≤ 3.25, which indicates a frequency of between rarely to sometimes / sometimes. The problems ranked joint fifth to joint twentieth have MSs > 1.75 ≤ 2.50, and therefore their frequency can be deemed to be between never to rarely / rarely. It is notable that inadequate design (support work / formwork), which is an upstream problem is ranked fourth. Given that the twenty-second ranked vibration from nearby plant MS > 1.00 ≤ 1.75, the frequency of occurrence can be deemed to be between never to rarely.

TABLE 3. FREQUENCY OF SUPPORT WORK / FORMWORK RELATED PROBLEMS.

Problem	MS	Rank
Damaged components	2.88	1
Inadequate fixing (ties)	2.60	2
Inadequate bracing	2.57	3
Inadequate design (support work / formwork)	2.56	4
Inadequate base / foundation	2.48	5=
Inadequate stays	2.48	5=
Inadequate jacks	2.48	5=
Loads (discharge heaping - concrete)	2.47	8
Inadequate fixing (nails / bolts)	2.33	9
Inadequate horizontal members	2.26	10
Premature stripping	2.23	11=
Pitting / Corrosion	2.23	11=
Loads (impact loads e.g. concrete bucket)	2.10	13=
Inadequate vertical members	2.10	13=
Loads (plant e.g. concrete pump)	2.09	15
Undermining (trenching)	2.06	16
Loads (people - excessive)	1.93	17
Loads (wind)	1.84	18
Substitution	1.83	19
Inadequate permanent design (concrete strength)	1.81	20=
Inadequate permanent design (reinforcing)	1.81	20=
Vibration from nearby plant	1.60	22

Table 4 indicates the frequency of support work and formwork related interventions, and the preparation of a project H&S plan in terms of percentage responses relative to

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a frequency range 'never' to 'always', and a MS between 1.00 and 4.00. Given that all the MSs > 2.50 the interventions can be deemed to generally be undertaken. Furthermore, all interventions have MSs > 2.50 ≤ 3.25, which indicates a frequency of between rarely to often / often. However, the mean score of formwork designs is marginally outside the range of > 3.25 ≤ 4.00.

TABLE 4. FREQUENCY OF SUPPORT WORK AND FORMWORK RELATED INTERVENTIONS.

Intervention	MS	Rank
Formwork designs	3.23	1
Support work layouts	3.18	2
Back propping layouts	3.00	3
Project H&S plan	2.87	4
Stripping schedule	2.79	5
Support work elevations	2.71	6

Table 5 indicates the basis of support work and formwork design in terms of percentage responses relative to a frequency range 'never' to 'always', and a MS between 1.00 and 4.00. Scientific calculations (outsource) (3.00) predominate in terms of the basis of design of support work and formwork. This is probably attributable to the lack of in-house expertise. MSs > 2.50 indicate that each respective basis can be deemed to be adopted, whereas the MS of 'rule of thumb' can be deemed to be generally not adopted. It is notable that experience can be deemed to be generally adopted, as it is not a scientific basis. MSs > 2.50 ≤ 3.25 indicate a frequency of between rarely to often / often.

TABLE 5. BASIS OF DESIGN OF SUPPORT WORK AND FORMWORK.

Basis	MS	Rank
Scientific calculations (outsource)	3.00	1
Experience	2.88	2
Scientific calculations (in-house – planning engineer)	2.68	3
Scientific calculations (in-house – contracts management)	2.65	4
Support work / Formwork subcontracted	2.56	5
Rule of thumb	1.78	6

Table 6 indicates the frequency of activities / interventions to ensure that support work / formwork conforms to requirements in terms of percentage responses relative to a frequency range 'never' to 'always', and a MS between 1.00 and 4.00. Given that 5 / 7 (71.4%) MSs are above the midpoint score of 2.50, the activities / interventions can be deemed to be generally conducted. It is significant that testing of materials, and testing of components have MSs > 2.50, which means that they can be deemed to be generally not conducted – significant in that these two interventions are critical in terms of assuring support and preventing failure. MSs > 3.25 ≤ 4.00, indicate a frequency of between often to always / always, and MSs > 2.50 ≤ 3.25, indicate a frequency of between rarely to often / often.

TABLE 6. FREQUENCY OF ACTIVITIES / INTERVENTIONS TO ENSURE THAT SUPPORT WORK / FORMWORK CONFORMS TO REQUIREMENTS.

Activity / Intervention	MS	Rank
Visual inspections (trade foreman)	3.59	1
Visual inspections (site agent)	3.53	2
Preventative maintenance (oiling)	3.50	3
Visual inspections (contracts manager)	3.39	4
Preventative maintenance (re-coating)	3.07	5
Testing of materials	2.24	6
Testing of components	2.10	7

Table 7 indicates the extent to which project contributors contribute to the overall quality management of support work / formwork in terms of percentage responses to design, quality assurance, quality control, and maintenance, and a mean. Contracts managers are the only contributor for which the mean percentage (51.4%) is > 50%, followed closely by site managers (48.6%). This is notable and supports the argument that support work and formwork are a construction management issue, as they are responsible for the physical construction process. It is also notable that they predominate in terms of design. Then, they along with foremen, they predominate in terms of quality assurance, and quality control. Plant yard predominates in terms of maintenance.

TABLE 7. EXTENT TO WHICH CONTRIBUTORS CONTRIBUTE TO THE OVERALL QUALITY MANAGEMENT OF SUPPORT WORK / FORMWORK.

Contributor	Response (%)					Rank
	Design	Quality assurance	Quality control	Mainte-nance	Mean	
Contracts managers	58.8	64.7	64.7	17.6	51.4	1
Site managers	47.1	50.0	70.6	26.5	48.6	2
Foremen	17.6	47.1	70.6	38.2	43.4	3
Support work / Formwork foremen	17.6	29.4	52.9	32.4	33.1	4
Plant yard	0.0	8.8	23.5	55.9	22.1	5
Workers	0.0	2.9	32.4	47.1	20.6	6
Structural engineer (design)	41.2	11.8	17.6	5.9	19.1	7=
Subcontractor	17.6	17.6	32.4	8.8	19.1	7=
Planning engineer	32.4	17.6	17.6	0.0	16.9	9
Project manager (lead consultant)	11.8	17.6	14.7	0.0	11.0	10
Architect	17.6	5.9	5.9	0.0	7.4	11

Table 8 indicates the frequency at which respondents' organisations experience support work / formwork and structures' related problems in terms of percentage responses relative to a frequency range 'never' to 'often' and a MS between 1.00 and 4.00. Given that all the mean scores are ≤ 2.50, the problems can be deemed to be generally not experienced. However, the MS of deflections (vertical plane - 'kicking') is on the midpoint, namely 2.50. 6 / 9 (66.7%) of the problems have MSs > 1.75 ≤ 2.50, which indicates that their frequency can be deemed to be between never to rarely / rarely.

TABLE 8. FREQUENCY AT WHICH RESPONDENTS' ORGANISATIONS EXPERIENCE SUPPORT WORK / FORMWORK AND STRUCTURES' RELATED PROBLEMS.

Problem	MS	Rank
Deflections (vertical plane - 'kicking')	2.50	1
Injuries e.g. cuts	2.47	2
Concrete 'honeycombing'	2.46	3
Deflections (horizontal plane)	2.20	4

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Musculoskeletal e.g. backache	2.16	5
Concrete 'cancer' (spalling)	1.83	6
Under-strength concrete	1.75	7
Collapses (support work)	1.60	8
Dermatitis (skin disease)	1.58	9

IV. Conclusions

Given that the respondents are likely to constitute the more committed GCs, the findings are likely to be biased in that the status reflected in the findings is unlikely to reflect the general level of performance, but rather that relative to the more committed GCs.

The traditional project parameters of quality, followed by productivity, are more important than H&S, schedule and environment to the respondents' organisations. Therefore, it can be concluded that the respondents' organisation understands and appreciates the importance of quality, which encapsulates H&S, and which impacts substantially on the other parameters should non-conformances occur.

Certain categories of problems relative to support work and formwork are experienced more frequently than others: damaged components; inadequate erection, and inadequate design. Load and permanent structure related problems are experienced less frequently.

Given the MSs of the support work- and formwork-related interventions, which indicate that in general the interventions can be deemed to be taken it can be concluded that the approach to support work and formwork is scientific to a degree.

Given the basis of design of support work and formwork it can be concluded that the approach to support work and formwork design is scientific to a degree.

Given that visual activities / interventions used to ensure that support work / formwork conform to requirements are more prevalent than tests, it can be concluded that quality management is more informal than formal.

Based upon the frequency of stakeholders' contributions to the overall quality management of support work and formwork, it can be concluded that contractors' management and supervision contribute more than designers thereto. Although it can be argued that designers are not intimately involved with support work and formwork, they do influence it. Furthermore, in terms of overall contributions in the form of design, quality assurance, quality control, and maintenance, it can be concluded that contractors' management and supervision contribute more than designers thereto.

Although the frequency at which organisations experience support work / formwork and structures' related problems can be deemed more infrequent than frequent, it can be concluded that problems do occur. More than a third of respondents indicated that deflections (vertical plane - 'kicking'), injuries e.g. cuts, and concrete 'honeycombing', sometimes occur. Therefore, us it can be concluded that support work per se, concrete, and H&S problems occur.

V. Recommendations

All support work and formwork should be scientifically designed. The erection of support work should be undertaken in accordance with documented systems, procedures, and protocol, and include periodic reconciliation with the design. Components should be examined before, during and after use, and be subjected to ad-hoc and planned maintenance

GCs should implement documented QMSs, which will complement construction in general, support work and formwork practices included.

Comprehensive support work and formwork education and training should be implemented. Civil engineering and Construction Management programmes should include support work and formwork design, either in a subject such as Structures or Construction Health and Safety. Other programmes such as Architecture and Quantity Surveying should address the generic issues relative to support work and formwork. Construction site management, supervisors included, should receive comprehensive support work and formwork training, which enables an understanding of the principles of design relative thereto, and the implementation of interventions to assure healthy and safe support work and formwork.

Workers should receive support work and formwork training, which enables an understanding of the basic principles of design relative thereto, and the salient interventions to assure healthy and safe support work and formwork.

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About Author (s):

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