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Ergonomics in Construction, Specifically in IDCs

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19.1 Introduction

According to Marmaras et al. (1999), while the science of ergonomics is a relatively recent phenomenon, there is evidence to suggest that ergonomics principles were known to the ancient Greeks. The word “ergonomics” is derived from two Greek words “ergon,” meaning work, and “nomos,” meaning laws. Today, however, the word is used to describe the science of “designing the job to fit the worker, not forcing the worker to fit the job” (Kroemer and Grandjean 1997); thus the science of adapting work and working conditions to suit the worker.

Ergonomics combines knowledge of human abilities with that of tool design, equipment, and work organization. According to Monk (2005), occupational ergonomics has to do with the design or modification of the workplace and the organization of work to match the worker. The aim of occupational ergonomics is to decrease injuries at the workplace and to improve productivity. Ergonomics principles can be applied at many stages of work design. They can be used in tool and equipment design, workplace layout, and the planning of work processes.

Schneider and Susi (1994) maintain that construction, by its very nature, is a problem for ergonomists as it requires work above shoulder level and below knee height. Materials may

also be heavy and/or inconveniently sized and shaped, thus presenting manual materials handling problems. According to Gibbons and Hecker (1999), numerous construction tasks pose significant risks to workers. The aim of this chapter is to consider the importance of ergonomics to the construction industry, as well as to identify work risks in construction, and point out the impact of even minimal ergonomics on the construction process. The chapter discusses the aspects which negatively affect the workers, and the interventions required in order to improve ergonomics in construction work processes.

19.2 Nature of Construction-Site Problems

Vedder and Carey (2003) contend the following are the most important safety, health, and ergonomically related problems in construction: accidents with construction tools; falling and tripping; manual handling, lifting, and carrying; noise; vibration; dust exposure; and poor design of tool interfaces. The University of Iowa (Center to Protect Workers Rights 1995) consulted approximately 2000 construction workers in the USA to determine where they hurt and the reason why. Of the job factors which constituted major ergonomically related problems, the following were the top four:

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- Bending or twisting the back
- Staying in the same position for long periods
- Working in the same position for long periods
- Handling heavy materials or equipment

Research conducted among construction workers representing six trades in the USA investigated inter alia, the extent to which 15 job factors constituted a problem on a scale of: minor-problem, minor-moderate problem, and major problem. Based upon a score out of 10, the following were determined to be the top five work-site problems resulting from little or no ergonomics input: working in the same position for long periods (5.7), bending or twisting the back in an awkward way (5.5), working in awkward or cramped positions (5.0), working when injured or hurt (4.7), and handling heavy materials or equipment (4.6) (Zimmerman et al. 1997).

A series of research studies conducted in South Africa investigated, inter alia, the frequency at which work problems were encountered (Smallwood 1997; Smallwood et al. 2000; Smallwood 2002). The problems are ranked in Table 19.1 based upon an importance index (II) with a minimum value of 0.0, and a maximum value of 4.0, which in turn was based upon percentage responses to a range "never" to "daily." The findings emanating from four sample strata surveyed during three studies are presented. The first study, which entailed the survey of both general contractors (GCs) and workers, was undertaken in 1997, the second study which entailed the survey of solely workers was undertaken in 2000, and the third study, which entailed the survey of "better practice" health and safety general contractors (BPGCs) was undertaken in 2002. An overall mean II, computed from the four sample strata, is also presented. It is notable that handling heavy materials, which achieved a ranking of third in South Africa, achieved a ranking of fourth and fifth in the respective US studies. Although the other respective top four ranked problems were not

TABLE 19.1
Frequency of Ergonomic Problems Encountered in South African Construction According to Management and Workers (II = 0–4)

Problem	GC (Smallwood, 1997)		Worker (Smallwood, 1997)		Worker (Smallwood et al. 2000)		BPGC (Smallwood, 2002)		Mean	
	II	Rank	II	Rank	II	Rank	II	Rank	II	Rank
Repetitive movements	3.29	1	3.56	1	2.97	3	3.78	1	3.40	1
Climbing and descending	2.88	2	3.01	4	3.23	1	3.56	2	3.17	2
Handling heavy materials	2.63	4 =	2.68	10 =	3.00	2	3.44	3	2.94	3
Use of body force	2.80	3	2.82	8	2.77	5	3.00	9	2.85	4
Exposure to noise	2.53	7	2.93	6	2.65	6	3.11	6 =	2.81	5
Bending or twisting the back	1.96	11	3.47	2	2.38	7	3.22	4 =	2.76	6
Reaching overhead	2.61	6	2.99	5	2.00	13	3.11	6 =	2.68	7
Reaching away from the body	2.41	8	3.19	3	2.03	12	2.63	12	2.57	8
Working in awkward positions	1.70	12	2.85	7	2.30	9	3.22	4 =	2.52	9
Handling heavy equipment	2.03	10	2.17	13	2.87	4	2.78	10	2.46	10
Working in hot conditions	2.29	9	2.68	10 =	2.15	10	2.33	13	2.36	11
Vibrating tools and equipment	2.63	4 =	1.43	16	1.96	14	3.11	6 =	2.28	12
Working in cramped positions	1.46	15	2.48	12	2.13	11	2.67	11	2.19	13
Staying in the same position for long periods	1.29	17	2.76	9	2.30	8	2.11	14	2.12	14
Working in humid conditions	1.60	13	1.53	15	1.66	17	1.89	15	1.67	15
Working in cold conditions	1.38	16	1.80	14	1.85	15	1.22	17	1.56	16
Working in wet conditions	1.57	14	1.21	17	1.70	16	1.67	16	1.54	17
Working while injured or hurt	0.19	18	0.84	18	0.48	18	0.44	18	0.49	18

Sources: Adapted from Smallwood, J.J., *J. Ergon. Soc. South Africa*, 9(1), 6, 1997; Smallwood, J.J., Deacon, C.H., and Venter, D.J.L., *J. Ergon. Soc. South Africa*, 12(1), 2, 2000; Smallwood, J.J., *J. Ergon. Soc. South Africa*, 14(1), 8, 2002.

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TABLE 19.2

Causes of Nontraumatic Injuries Relative to Age

Age	Causes of Nontraumatic Injuries												Total No.
	Repetitive		Awkward Posture		Fixed Posture		Heavy		No Breaks		Other		
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
<20	4	28.6	4	28.6	0	0.0	3	21.4	3	21.4	0	0.0	14
20–30	17	41.5	11	26.8	4	9.8	4	9.8	3	7.3	2	4.9	41
30–40	15	28.9	10	19.2	9	17.3	9	17.3	6	11.5	3	5.8	52
40–50	12	25.0	12	25.0	4	8.3	9	18.8	6	12.5	5	10.4	48
Total	48	31.0	37	23.9	17	11.0	25	16.1	18	11.6	10	6.5	155

Source: Ramana, K.R. and Satyanarayana, K.N., *Proceedings of the 4th Triennial International Conference Rethinking and Revitalising Construction Safety Health Environment and Quality*, pp. 461–469, Port Elizabeth, South Africa, May 17–20, 2005.

common to both South Africa and the USA, bending or twisting the back, which achieved a ranking of second in the USA, achieved a ranking of sixth in South Africa. Furthermore, in terms of the top ranked South African problems, the following should be noted: repetitive movements are more likely in a country such as South Africa, which makes predominant use of masonry materials for walls, than a country that makes use of prefabricated framing and panels such as the USA. Climbing and descending are more likely in a country which makes limited use, if any, of vertical transportation of people as with personnel hoists, than in a country that does.

More recent trade-specific research conducted in the Western Cape, South Africa, among bricklayers, plasterers, painters, and their respective assistants, identified neglected ergonomics issues (Samuels et al. 2006). The problems include: bending and twisting of the body; reaching away from the body and reaching overhead; working in awkward positions; lifting and manually handling heavy and irregularly sized and shaped materials and components; working below knee level; and working while kneeling. Most of these activities also involved working at extreme ranges in challenging environments. A study conducted in Hyderabad, India by Ramana and Satyanarayana (2005) identified the causes of nontraumatic injuries, where repetitive movements predominated, followed by awkward postures (see Table 19.2).

19.3 Trade-Related Problems and Ergonomics Solutions: A Case Study

Schneider and Susi (1994) reviewed the findings of a team of industrial hygienists who followed the construction of a four-storey office building for the 15 months duration of the project. In relation to the various trades, the following examples are a summary and provide an indication of the work hazards which result from the construction process and possible poor design, together with the ergonomics-related solutions (in *italics*) which mitigate or eliminate the hazard.

Concreting: Shoveling and smoothing the surface of concrete are strenuous on the lower back. *The addition of plasticizers improves concrete workability.*

Reinforcing: The fixing and tying of bar reinforcing require bending and a great deal of rapid repetitive twisting of the wrist, the latter resulting in the development of ganglion cysts.

The use of fabric, in lieu of bar reinforcing, reduces the amount of time spent fixing and tying reinforcing per concrete element, and the amount of bending and rapid repetitive twisting of the wrist. Using trestles also enables steel fixers to fix cages at "worktop" level.

Formwork: The erection and striking of support-work and form-work require a large amount of bending, twisting, and use of body force.

Designers can facilitate the use of composite systems through the simplification of design, table forms, and wall forms which can be handled by craneage, thereby reducing the manual aspect of an activity. The use of precast concrete also reduces the amount of support-work and form-work, and on-site fixing and tying of reinforcing required. Prestressed concrete elements, particularly slabs, also reduce the amount of bar reinforcing.

Structural steelwork: Problems associated with the erection thereof include awkward postures, occasional high force requirements, static postures, repetitive movements, use of pneumatic tools, and lifting. The high risk nature of the activity which entails straddling beams several meters in the air while aligning and bolting together columns and beams compounds the problems.

Preassembly, simplified joints, and integral safety features can reduce the hazards.

Masonry: Block and brick laying represent major work hazards in building. Lifting an average of 1000 bricks a day is the equivalent to lifting 2300–4000 kg, and 1000 trunk-twist flexions.

A construction-related intervention includes the provision of waist high materials platforms. Design improvements include the incorporation of hand-holds in blocks to facilitate lifting. Alternative wall systems constitute the optimum solution.

Roofing: Roofing poses many different hazards due to minimal ergonomic input, but the prime one is materials handling. Of the three types of roofing, unit and sheet materials and waterproofing membranes, unit materials require considerably more bending, twisting, and handling of mass per square meter of covered area, than sheet materials.

The use of "ladder type" tile lifts facilitates the lifting of unit materials to roof level.

Building fabric: Differing systems and materials pose differing problems. Concrete surface finishes such as bush-hammering present a risk of hand-arm vibration and health problems such as silicosis. Natural stone claddings require a lot of lifting and hoisting of panels, adopting of awkward postures and hand-arm vibration as a result of fixing, presenting a risk of back injury and hand/wrist problems.

Design alternatives include light weight sheet metal claddings and curtain walling, which will minimize the risk factors.

Plumbing and drainage/pipefitting: Piping is often at odd angles and in cramped spaces. Specific piping materials have specific jointing methods, not all of which are complementary to basic ergonomics principles. A number of installations are suspended and require extensive overhead work, the fixing of the suspension hangers resulting in substantial stretching and twisting, and consequently a high level of stress on the neck and shoulders of workers.

Designers should consider the ergonomic implications of jointing methods when specifying materials, the feasibility of prefabricated stacks, and horizontal and vertical service ducts for piping.

Electrical: Electricians often work in cramped postures and their work entails a large amount of wrist action resulting in stress on the arm and shoulders. Making connections requires extensive use of hand-tools, often in cramped spaces such as ceilings above and between ducting and other piping.

Designers should make adequate provision for access during both design and coordination of services during design.

Floor finishes: All floor finishes require constant kneeling and bending. Ceramic and similar tile and terrazzo work entail additional risk. Often the weight of the tiles to be set can be substantial, particularly in the case of natural stone. Terrazzo and similar finishes require considerable hand and wrist motion.

When specifying finishes, designers should consider the nature of processes pertaining thereto. Using trestle type work benches reduces the need for tilers to cut at floor level.

Suspended ceilings: Most suspended ceilings require significant overhead work although the components are not particularly heavy. It is necessary to suspend primary tracks from hangers and secondary tracks between the primary tracks. Screw-up suspended ceilings require considerably more overhead work than lay-in tile ceilings.

Consequently, designers should specify the latter where possible. The use of mobile tower scaffolds with full work platforms is more complementary to ergonomics than the use of ladders.

Painting and decorating: Overhead painting of ceilings places considerable stress on the arms and shoulders, as well as the neck.

Designers should consider self-finishes where possible.

Paving and other external work: Brick paving requires work similar to that of tiling. In addition, pavers often have to be cut with an electrically powered masonry saw which requires working at ground level, and consequently requires the workers to bend a great deal.

The use of work-bench type masonry saws does reduce the hazard. Although asphalt paving exposes workers to whole-body and hand-arm vibration, workers are not exposed to the volume of repetitive movements and other work-related postures as in the case of brick paving.

19.4 Trade-Related Problems and Ergonomic Solutions

According to Hsiao and Fosbroke (1997), an analysis of injury data indicates that 11 occupations are "at increased risk" as they represent 31% of the workforce, but account for 62% of the overexertion injuries. The occupations are general workers, carpenters, plumbers, drywall installers, roofers, electricians, structural metal workers, carpet layers, tile setters, plasterers, and machine operators. Among these occupational groups, there have been greater numbers of reported musculoskeletal disorders due to limited use of ergonomics within the work-site (Rwamamara 2005a). In recent years, the industrialization of the construction industry has been conveyed as a way of improving ergonomics in the construction workplace. However, industrializing the industry has in fact also created numerous problems in making changes in the construction work environment (Rwamamara

2005a). If changes are primarily motivated by the need to save money and the promise of increased productivity, workers may be resistant to changes, as higher productivity means more work with fewer workers (Schneider 1999). Workers along with other stakeholders in the production process need to be included in the identification of high risk tasks and potential solutions. Then, the industrialization of construction work could be said to be successful in terms of both building quality and financial gain for employers and clients, plus a safer and healthier work environment for the construction workers.

Research conducted among general contractors in South Africa investigated the impact of 23 traditional trades and activities on construction ergonomics (Smallwood 1997). Table 19.3 indicates the impact of the trades and activities based upon an II with a minimum value of 0.0, and a maximum value of 3.0, ranked from greatest to least impact. The findings are notable in that although the IIs are <1.5 and the activities/trades can thus be deemed to have no or a minor impact as opposed to a major impact, the activities/trades do in fact all have an ergonomics effect, which indicates that the respondents do not have an understanding and appreciation of the impact of the activities/trades. In fact, activities or trades such as excavating, formwork, concreting, roofing, steel erecting, screeding, and bricklaying all require repetitive movements, use of body force, and

TABLE 19.3

Extent to Which Activities/Trades Impact on Construction Ergonomics according to Management

Activity/Trade	Impact (%)					II	Rank
	Don't know	No	Minor	Moderate	Major		
Excavating	3.7	18.5	27.2	33.3	17.3	1.46	1
Formwork	5.1	21.5	27.8	31.7	13.9	1.33	2
Concreting	4.9	21.0	29.6	30.9	13.6	1.32	3
Roofing	9.0	14.1	28.2	43.6	5.1	1.31	4
Plant operating	7.7	19.5	28.6	31.2	13.0	1.29	5
Steel erecting	15.6	20.7	23.4	24.7	15.6	1.15	6 =
Screeding	7.6	27.8	26.6	25.3	12.7	1.15	6 =
Bricklaying	6.3	26.7	27.8	32.9	6.3	1.13	8 =
Ceiling erecting	9.1	28.6	20.7	32.5	9.1	1.13	8 =
Block laying	10.0	27.5	22.5	33.7	6.3	1.09	10
Carpentry	7.7	28.6	27.3	29.9	6.5	1.07	11
Plastering	7.5	30.0	27.5	26.3	8.7	1.06	12 =
Reinforcing	12.8	21.8	34.6	20.5	10.3	1.06	12 =
Pipe laying	24.4	19.2	21.8	25.6	9.0	1.00	14
Paving	12.0	26.7	36.0	20.0	5.3	0.92	15
Painting	12.8	29.5	33.3	19.3	5.1	0.87	16
Waterproofing	17.1	23.7	38.2	15.8	5.3	0.86	17 =
Joinery	17.1	26.3	32.9	18.4	5.3	0.86	17 =
Ducting	28.6	24.6	27.3	11.7	7.8	0.74	19
Pipe fitting	32.1	20.5	32.1	11.5	3.8	0.67	20
Floor coverings	20.0	32.0	32.0	14.7	1.3	0.65	21
Glazing	25.0	27.6	34.2	11.8	1.4	0.62	22
Fencing	24.0	30.7	30.7	13.3	1.3	0.61	23

Source: Smallwood, J.J., *J. Ergon. Soc. South Africa*, 9(1), 6, 1997.

reaching away from the body. Furthermore, even though the highest levels of “don’t know” responses are relative to subcontract activities/trades, the management of general contractors should be aware of the ergonomically related risks.

19.4.1 Solutions through the Influence of Clients and Designers

19.4.1.1 Clients

Clients influence construction risks both directly and indirectly. Directly in that they often select the type of structural frame, fabric, materials, and finishes. Indirectly through the selection of site; decision on project duration; prioritization of health and safety (HS); financial support of contractors’ HS efforts; prequalification of contractors on health and safety HS; establishing project HS requirements; requiring of project HS plans; and conducting HS audits (Smallwood 1998). The cost of accidents and the influence of ergonomics on project performance constitute an incentive to clients to contribute to contractor HS and ergonomics.

19.4.1.2 Designers

Designers influence ergonomics directly in that they produce the following aspects: the concept design, select the type of structural frame and fabric, undertake the detailed design, prepare details and specify materials; the type of structural frame affects the nature, scope, and logistics of the work, i.e., reinforced concrete versus structural steel; the type of structural frame, building fabric and finishes affect the nature of, and demand for means of ascending/descending, walkways and working platforms; the mass, volume, surface area, texture, edges, contents, and type affect the manner in which materials are handled; the characteristics of materials, along with configuration, affect the suitability of elements and components to be mechanically handled; the characteristics of materials affect materials storage requirements and housekeeping; plus the site coverage affects the availability of space for material storage, circulation paths, and roads (Smallwood 2000a). Designers also influence ergonomics indirectly through choice of procurement system, effectiveness of design coordination, the use or nonuse of prequalification of contractors, selection of contractor, and project duration (Smallwood 2000b). Certain procurement systems, such as design-build, engender ergonomics as a result of the integration of design and construction. Optimum design coordination of aspects such as services enhances ergonomics through optimum working space in ducts, and ceiling and roof spaces. Prequalification engenders the engagement of ergonomics conscious contractors. Project duration, if shortened to the extent that it results in a disproportionate amount of resources in the workplace, negatively affects ergonomics as a result of congestion. For many of these construction-site problems, ergonomic solutions have been proposed (Schneider and Susi 1994), some of which can help reduce the risk factors present, and others which hold promise as interventions (Table 19.4).

19.5 Impact of Stages of Projects on Construction Ergonomics

Research conducted among general contractors in South Africa investigated the impact of the general 10 stages of projects on construction ergonomics (Smallwood 2002). Respondents were required to respond relative to a five-point scale ranging from a minor

TABLE 19.4**Solutions to Ergonomics Problems**

Ask	Solution
Heavy equipment operator	Better seat design
Vibration	Better handle design
Shoveling	Adjustable scaffolds
Laying masonry blocks	Keep brick stack at proper height
	Pump mortar to point of application
	Limit weight of blocks
	Redesign blocks with hand holds
	Better handle design
Carrying buckets of cement	Adjustable height saw horses
Formwork	Bent handle hammer design
	New forms that are easier to dismantle
	Use of smaller form components
	Enclosed cabs, better seat design
Crane operation	Tool for tying rods from standing height
Concrete floor work	Straight edge handle
	Welded fabric nets
	Vibration/noise dampened equipment
Chipping hammer vibration	Lighter weight models
	Attachment of sprayers to self for support
Spraying fireproofing	Use of hoist to crank ductwork to proper height
Installation of ductwork	Install on side wall rather than overhead in utility tunnels
Plumbing installation	Better design handles
Electrical work-screwdriving	Use of powered screwdrivers
	Use of TORX head screws
	Micropauses during continuous work
	Use of drill stand or bolt gun waist belt for overhead work
Drywall installation	Use of dollies, carts to transport boards
	Use of narrower boards (90 cm)
	Use of handles, proper training
	Use of swivel-head screw guns
	Plasterboard lifts
Elevator construction	Use of dollies, carts, lifting hooks, and better planning
	Use of cranes, dollies, smaller tubes of asphalt, better bucket handles
	Use of asphalt tanker rather than kettle
Building exterior	New tool for fastening roof from standing height
	Use of motorized scaffold, sheet clad storage device
Scaffold erection	Mechanical window installation device
	Use of hoists, newer scaffolds that are easier to carry and assemble
Painting	Flange on painters handle and neck pillow for overhead work
Installation of ceiling grid	Redesign of bucket handle and bucket

(Continued)

TABLE 19.4 (Continued)

Solutions to Ergonomics Problems

Ask	Solution
Floor glue spreading	Materials in smaller packages with handles
Carpet laying	Use of better hand tools, powered screwdrivers
	Use of standing spreader tool
Work at floor level	Use of power stretches instead of knee kicker
	Dollies for carpet rolls
Door installation	Use of wheeled stools with tool bins
	Combination knee pad/seat for kneeling work
Setting paving stones	Border drills
	Foot levers
Asphalt paving	Mechanical door installer
	Dolly for setting stones
	Better machines with less vibration

Source: Schneider, S. and Susi, P., *Am. Indust. Hygiene Assoc. J.*, 55(7), 635, 1994.

to a major impact. Eight of the ten stages were deemed to have more of a major than a minor impact: structural steel structures; reinforced concrete structures; roof; cladding/external fabric; installation of services (structure); ceilings; walling/partitions; and external works. Finishes, site clearance, and earthworks were deemed to have a minor impact. A comparative study conducted in India and South Africa investigated a range of ergonomics issues (Smallwood and Haupt 2007). Table 19.5 indicates the extent to which the various stages of projects impact on construction ergonomics in terms of a mean score ranging between 1.0 and 5.0 based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that the average of all the mean scores is above the midpoint score of 3.0, which indicates that the stages can be deemed to generally have more of a major than a minor impact on construction ergonomics. However, in terms of ranges, given that the means of the mean scores for those stages ranked first to ninth are $>3.4 \leq 4.2$, they can be deemed to have between a major/near major impact on construction ergonomics. The average of the mean scores relative to walling/partitions indicates that it can be deemed to have less impact on construction ergonomics.

The relevance of these findings is that all project stakeholders need to focus on the stages which have the greater impact on construction ergonomics. Focus includes hazard identification and risk assessment, and if possible amendment of the design, and/or details, and/or specification, and adoption of alternative methods of work and organization of the work place.

The extreme right-hand column in Table 19.5 (as in Tables 19.6 and 19.8) presents the percentage difference (the ratio of the higher to the lower mean score, as registered on a scale of 1.0–5.0). It is noteworthy that in all stages listed in Tables 19.5, 19.6, and 19.8, the higher recorded mean score is relative to South Africa. The stages with percentage differences:

- 20% are installation of services (structure) (32.4%); ceilings (23.8%); cladding/external fabric (23.3%); and walling/partitions (20.5%).
- $10\% \leq 15\%$ are finishes (13.2%); structural steel structure (11.3%); and reinforced concrete structure (10.8%).

TABLE 19.5

Extent of Impact of the Various Stages of a Project on Construction Ergonomics

Stage	India		South Africa		Mean		Difference (%)
	MS	Rank	MS	Rank	MS	Rank	
Structural steel structure	3.82	1	4.25	1	4.03	1	11.3
Reinforced concrete structure	3.78	2	4.19	3	3.98	2	10.8
Roof	3.69	3	3.97	5 =	3.83	3	7.6
Installation of services (structure)	3.18	9	4.21	2	3.70	4	32.4
External works	3.53	4	3.85	7	3.69	5	9.1
Ceilings	3.28	6	4.06	4	3.67	6	23.8
Cladding/external fabric	3.22	8	3.97	5 =	3.59	7	23.3
Site clearance and earthworks	3.45	5	3.61	9	3.53	8	4.6
Finishes	3.26	7	3.69	8	3.48	9	13.2
Walling/partitions	2.89	10	3.55	10	3.22	10	22.8

Source: Smallwood, J.J. and Haupt, T.C., *J. Ergon. Soc. South Africa*, 19(1), 30, 2007.

19.6 Effect of Design, Procurement, and Construction Aspects on Ergonomics

The comparative study conducted in India and South Africa also investigated the extent to which various design, procurement, and construction aspects affect construction ergonomics (Smallwood and Haupt 2007). Table 19.6 indicates the extent to which they do in terms of mean scores ranging between 1.0 and 5.0, based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that the means of the mean scores of all

TABLE 19.6

Extent to Which Aspects Negatively Affect Construction Ergonomics

Aspect	India		South Africa		Mean		Difference (%)
	MS	Rank	MS	Rank	MS	Rank	
Degree of contractor awareness relative to ergonomics	3.89	1	4.26	2	4.07	1	9.5
Standard of site house keeping	3.40	4	4.31	1	3.86	2	26.8
Degree of contractor planning	3.50	2	4.13	3	3.81	3	18.0
Amount of work relative to project duration	3.41	3	3.91	6	3.66	4	14.7
Degree of mechanization	3.19	8	4.03	4	3.61	5	26.3
Format of materials	3.21	6 =	3.94	5	3.57	6	22.7
Specification	3.21	6 =	3.61	8	3.41	7	12.5
Details	2.98	9	3.65	7	3.31	9	22.5
Type of procurement system	3.27	5	3.25	10	3.26	7	0.6
General design	2.86	10	3.56	9	3.21	10	24.5

Source: Smallwood, J.J. and Haupt, T.C., *J. Ergon. Soc. South Africa*, 19(1), 30, 2007.

the aspects are above the midpoint score of 3.0, which indicates that the aspects can be deemed to generally have more of a major than a minor impact on construction ergonomics. However, in terms of ranges, given that the means of the mean scores for those stages ranked first to seventh are $>3.4 \leq 4.2$, they can be deemed to have between a major/near major impact on construction ergonomics. The degree of contractor awareness relative to construction ergonomics, standard of site housekeeping, degree of contractor planning, and degree of mechanization are construction-related aspects. However, the degree of mechanization is influenced by design, and the amount of work relative to project duration is procurement related, and is influenced by clients and principal agents. Format of materials is manufacture related, and specification design related. The means of the remaining three aspects are $>2.6 \leq 3.4$, and therefore the aspects can be deemed to have between a near minor impact to impact/impact on construction ergonomics—details, procurement system, and general design.

In Table 19.6, it is noteworthy that in every case the higher mean score is relative to South Africa. The aspects with percentage differences: $>20\%$ are standard of site housekeeping (26.8%); degree of mechanization (26.3%); general design (24.5%); format of materials (22.7%); and details (22.5%); $>15\% \leq 20\%$ are degree of contractor planning (18%), and $> 10\% \leq 15\%$ are amount of work relative to project duration (14.7%) and specification (12.5%).

19.7 Aspects Which Require Attention

Previous research conducted in South Africa investigated the extent to which various aspects of construction had an impact on ergonomics require attention (Smallwood 1997). Table 19.7 presents the findings according to management and workers, ranked in terms of most to least attention, based upon the mean percentage of affirmative response. Although the aspects are all construction related, designers essentially influence most aspects. Designers influence materials directly in that they evolve the design concept, select the

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TABLE 19.7

Construction Ergonomic Related Aspects Which Require Attention According to Management and Workers

Aspect	Management		Workers		Mean	
	Yes (%)	Rank	Yes (%)	Rank	Yes (%)	Rank
Materials handling	78.8	3=	76.3	1	77.6	1
Working platforms	81.7	2	70.5	3	76.1	2
Housekeeping	78.8	3=	70.8	2	74.8	3
Means of ascending/ descending	83.8	1	65.6	5=	74.7	4
Materials storage	74.1	5	69.7	4	71.9	5
Walkways	71.8	6	65.6	5=	68.7	6
Mechanization	64.9	7	50.4	7	57.7	7
Circulation paths	53.2	8	41.3	8	47.3	8
Circulation roads	51.3	9	37.2	9	44.3	9

Source: Smallwood, J.J., *J. Ergon. Soc. South Africa*, 9(1), 6, 1997.

type of frame and fabric, undertake the design, prepare details, and specify materials. Designers influence materials handling and mechanization directly through the conceptual design, choice of structure, design in general, details, and specification of materials. The mass, volume, surface area, texture, edges, contents, and type affect the suitability of elements and components to be mechanically handled. The characteristics of materials affect materials storage requirements and housekeeping. Site coverage affects the availability of space for materials' storage, circulation paths, and roads. The type of building fabric and finishes affects the nature of, and demand for means of ascending/descending, walkways, and working platforms.

19.8 Multi-Stakeholder Interventions

The ergonomic and general HS benefits of multi-stakeholder solutions and interventions have been advocated before in a systematic method for identifying hazards and operability problems in a facility (Lingard and Rowlinson 2005). Furthermore, a participatory design involving all stakeholders was suggested to establish a healthy and safe construction workplace over and above the enhanced productivity and quality (Rwamamara and Holzmann 2007). The comparative study, conducted in India and South Africa, also investigated the extent to which various design and construction aspects could contribute to an improvement in construction ergonomics (Smallwood and Haupt 2007). Table 19.8 indicates the extent to which aspects could contribute to an improvement in construction ergonomics in terms of mean scores ranging between 1.0 and 5.0, based upon percentage responses on a scale of 1 (minor) to 5 (major). It is noteworthy that the means of all the mean scores

TABLE 19.8

Extent to Which Aspects Could Contribute to an Improvement in Construction Ergonomics

Aspect	India		South Africa		Mean		Difference (%)
	MS	Rank	MS	Rank	MS	Rank	
Awareness	4.63	1	4.52	4	4.57	1	2.4
Safe working procedures	4.35	2	4.55	1 =	4.45	2	4.6
Contractor planning	3.99	3	4.55	1 =	4.27	3	14.0
Workshops on site	3.85	6	4.42	6	4.14	4 =	14.8
Mechanization	3.82	7	4.45	5	4.14	4 =	16.5
Constructability (general)	3.73	8	4.53	3	4.13	6	21.4
Design of equipment (construction)	3.86	5	4.30	8	4.08	7	11.4
Reengineering	3.90	4	4.19	11	4.05	8	7.4
Prefabrication	3.66	10	4.31	7	3.99	9	17.8
Design of tools	3.61	11	4.27	9	3.94	10	18.3
Specification	3.68	9	4.09	12	3.89	11	11.1
Details	3.61	12	4.03	13	3.82	12	11.6
General design	3.21	13	4.22	10	3.71	13	31.5

Source: Smallwood, J.J. and Haupt, T.C., *J. Ergon. Soc. South Africa*, 19(1), 30, 2007.

are above the midpoint score of 3.0, which indicates that the aspects can be deemed to generally have the potential to contribute to a major, rather than a minor improvement in construction ergonomics. Furthermore, it is significant that the means of three of the 12 aspects are $>4.2 \leq 5.0$, which indicates that the aspects can be deemed to have between near major and major potential to contribute to an improvement in construction ergonomics. Although awareness is generic, safe working procedures and contractor planning are contractor-related aspects.

The means of the remaining aspects are $>3.4 \leq 4.2$, and therefore they can be deemed to have near major potential to contribute to an improvement in construction ergonomics. Although workshops on site and mechanization are contractor-related aspects, the degree of mechanization is influenced by design. Constructability (general) prefabrication, specification, details, and general design are design-related aspects. However, they are influenced by clients, project managers, and quantity surveyors. Design of equipment (construction) and design of tools in turn are manufacturer related. Reengineering is a design/procurement/construction-related aspect that is influenced by all project stakeholders, i.e., clients, project managers, quantity surveyors, general contractors, cocontractors, suppliers, and manufacturers. The extreme right-hand column calculated as discussed above again shows higher scores from South African respondents compared with the Indian respondents. The aspects with percentage differences:

- 20% are general design (31.5%) and constructability (21.4%)
- $15\% \leq 20\%$ are design of tools (18.3%); prefabrication (17.8%); and mechanization (16.5%)
- $10\% \leq 15\%$ are workshops on site (14.8%); contractor planning (14%); details (11.6%); design of equipment (construction) (11.4%); and specification (11.1%)

The nature and scope of a “Where does it hurt?” research project conducted among workers in South Africa presented the opportunity to investigate the relationship between the work-site problems encountered and the ergonomics-related aspects which require attention (Smallwood et al. 2000a). These research projects identified the relationships which were either statistically significant in terms of association or dependence, or both. It is notable that 9 of the 13 (69.2%) relationships presented involve requiring attention to mechanization. It is significant that 7 of the 9 (77.8%) were statistically significant in terms of both ordinal scale scores and observed frequencies. It is also notable that in terms of aspects requiring attention, three (23.1%) of the 13 relationships presented involved materials handling, and in terms of problems, 4 (30.8%) of the 13 relationships involved handling heavy equipment or heavy materials.

In a US case study identifying multi-stakeholder ergonomics interventions used to reduce musculoskeletal loading for building installation tasks (Albers et al. 2005), it was found that engineering interventions described in stakeholder meetings included tools, equipment, and engineered building materials; administrative controls largely consisted of training and education programs; and modifications of work and management practice. However, most participants believed that there were significant limits to the impact individual contractors and trades people could have in facilitating ergonomics improvements in the building and construction industry. Furthermore, in a study on the impact of the industrialized construction process on the health of construction workers and ergonomics in the construction workplace, it was found that the production process had a positive impact in improving the construction work environment in terms of reduction of risk factors conducive

to musculoskeletal disorders; nonetheless the quasi-nonexistent worker consultation on health measures made the industrialization less optimal (Rwamamara 2005b).

19.9 Summary

A range of ergonomically related problems are encountered in IACs as well as IDCs in relation to construction. Furthermore, all trades and activities contribute to the existence of such problems. Many of these problems have their origin in the nature of work processes which are far more suboptimal in IDCs as they are exacerbated by using a manual approach when a mechanical approach would be more appropriate. Mechanization thus constitutes a potential holistic intervention, which is complemented and facilitated by prefabrication and preassembly. However, this will require a paradigm shift in developing countries, which invariably view construction as a creator of employment in terms of labor intensive construction. Although such a perspective may be noble in terms of intentions, it is not sustainable and results in the marginalization of people's health and well-being through the onset of musculoskeletal disorders.

Research indicates that ergonomics factors are impacted upon by design, procurement, and construction, and thus solutions require a multi-stakeholder approach incorporating clients, project managers, designers, quantity surveyors, contractors, and material manufacturers and suppliers. Invariably a catalyst is required to realize change. Awareness constitutes the catalyst, which in turn entails a prerequisite in the form of education and training. Therefore, the onus resides with educators and trainers involved in construction work, and all tertiary level environment and skills training programs should address construction ergonomics.

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AUTHOR QUERIES

[AQ1] 'Center to Protect Workers Rights (1995)' is not provided in list. Please check.

[AQ2] Please check whether 'With permission' is needed for all source lines in Tables 19.1–19.8.

[AQ3] Please check the sentence "Previous research conducted in South Africa..." for sense.