

Mass of materials: the impact of designers on construction ergonomics

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Abstract. Many construction injuries are musculoskeletal related in the form of sprains and strains arising from the handling of materials, which are specified by designers. The paper presents the results of a study conducted among delegates attending two 'designing for H&S' (DfH&S) seminars using a questionnaire. The salient findings include: the level of knowledge relative to the mass and density of materials is limited; designers generally do not consider the mass and density of materials when designing structures and elements and specifying materials; to a degree designers appreciate that the mass and density of materials impact on construction ergonomics; designers rate their knowledge of the mass and density of materials as limited, and designers appreciate the potential of the consideration of the mass and density of materials to contribute to an improvement in construction ergonomics. Conclusions include: designers lack the requisite knowledge relative to the mass and density of materials; designers are thus precluded from conducting optimum design hazard identification and risk assessments, and tertiary built environment designer education does not enlighten designers relative to construction ergonomics. Recommendations include: tertiary built environment designer education should construction ergonomics; professional associations should raise the level of awareness relative to construction ergonomics, and design practices should include a category 'mass and density of materials' in their practice libraries.

Keywords: construction ergonomics, designers, materials

1. Introduction

The South African Construction Regulations [1] define ergonomics as "the application of scientific information concerning humans to the design of objects, systems and the environment" for human use in order to optimise human well-being and overall system performance.

Materials may be heavy and / or inconveniently sized and shaped, thus presenting manual materials handling problems [2]. However, the Construction Safety Association of Ontario (CSAO) [3] is more specific and states that pain in the back and joints is a major factor in forced retirement from construction and workers seeking less demanding occupations, and that 62% of back injuries are attributable to manual materials handling. The Health & Safety Executive (HSE) [4] underscore the CSAO's findings with

the statistic that every year one-third of all construction industry accidents reported to the HSE in the United Kingdom (UK) involve manual handling.

Hazards and risks that arise during construction, such as handling heavy materials, can be mitigated by designers, as designs develop from initial concepts through to a detailed specification [5]. Designing for H&S is an integral part of the wider design process [6], and H&S through design is a fundamental principle of ergonomics [7]. 'H&S through design' is a familiar concept to occupational hygienists in that they invoke the hierarchy of controls that is fundamental to the process of hazard reduction [8]. Substitution is included in the hierarchy, which includes the substitution of heavy materials with a lighter alternative. However, although architects and engineers regularly address ergonomics in their designs, it is invariably focused almost exclusively on

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the end-user of a facility, rather than the workers who construct it.

The reality is that materials are specified by designers, and therefore they directly influence the mass of materials that construction workers have to handle, position, and fix. Furthermore, project managers coordinate design delivery, and integrate design and construction, and thus are ideally positioned to review specifications. The mass of materials provides an instant indication to designers of the load that has to be lifted provided they are conscious of the issue, and know or source the mass. However, when determining the mass of a non-standard component such as a marble panel, the specifier needs to have a heightened level of consciousness and relate density to the size of the component. Given the aforementioned, and the potential role of designers and project managers to mitigate hazards such as heavy materials and components, the paper reports on a study 'mass and density of materials' conducted among delegates attending two 'designing for H&S' seminars, the objectives of which were to determine the:

- Level of knowledge relative to the mass and density of materials;
- Perceptions relative to the mass and density of materials, and
- Practices relative to the mass and density of materials.

2. Literature review

2.1. *The need for ergonomics*

There is a paucity of South African statistics; however, international statistics provide insight relative to MSDs in construction. MSDs accounted for 13% of absences from work in the Republic of Ireland during the period January 1981 and August 1996, the predominant disorder being back pain / ache (59.7%) [9]. Many of the injuries and illnesses that affect construction workers in Australia are MSDs, which are primarily labeled as sprains and strains. Furthermore, manual handling injuries accounted for 33.8% of all workplace injuries in Australia for the period 1998-1999 [2].

The leading type of non-fatal injury and illness in terms of days away from work in the United States construction industry in 2005 was sprains and strains (34.7%), and in terms of anatomic regions, the back (19.2%) predominated. Overexertion in lifting accounted for 41.7% of work-related MSDs resulting in days away from work in 2005 [10].

2.2. *Recommendations and legislation pertaining to architects and architectural technologists*

With respect to legislation, Section 10 of the Occupational Health and Safety Act (OH&S Act) [11] allocates designers the responsibility to ensure that any 'article' is safe and without risks when properly used. Although this requirement was not explicit, the Construction Regulations [1], which were intended to engender a paradigm shift, are, as clients and designers are specifically required to address construction ergonomics and H&S. Clients are required to, inter alia, prepare H&S specifications for construction work, and provide principal contractors (PCs) with any information that might affect H&S. This includes residual risk in the form of heavy materials. Though these requirements pertain to clients, they invariably require the input of designers given that: designers may specify materials that are heavy and thus constitute a hazard due to the non-availability of alternative materials. Designers in turn are required to, inter alia: inform PCs of any known or anticipated dangers or hazards or special measures required for the safe execution of the works, and modify the design or make use of substitute materials where the design necessitates the use of dangerous structural or other procedures or materials hazardous to H&S. These requirements implicitly require that designers conduct hazard identification and risk assessments, which in turn requires that designers are knowledgeable relative to the mass of materials, and that where alternative designs and specifications are not possible, that residual hazards are identified in the H&S specification.

2.3. *The impact and role of designers in construction ergonomics*

Designers can contribute to construction H&S through five specific tasks, inter alia, review for H&S, and design for H&S. In terms of review for H&S, a constructability review would ensure that the design provides an acceptable level of worker H&S through consideration of, inter alia, consideration of the mass and density of materials and components as they need to be handled and positioned. Design for H&S should include consideration for H&S throughout the design process.

2.4. *Impact of design on construction ergonomics*

Design decisions directly affect construction H&S as the way designers, inter alia, select materials, influences the way the work will be performed by workers [12].

Two research projects conducted in South Africa investigated, *inter alia*, the impact of design on construction ergonomics. A self-administered postal survey conducted among a group of better practice H&S general contractors investigated, *inter alia*, the extent to which various design aspects impact on construction ergonomics. The extent in terms of a mean score ranging between 1.00 (minor impact) and 5.00 (major impact) included, *inter alia*, format of materials (3.89); details (3.44), and specification (3.44) [13]. A more recent self-administered survey conducted among built environment practitioners during construction ergonomics seminars investigated, *inter alia*, the extent to which aspects negatively affect construction ergonomics. The extent in terms of a mean score ranging between 1.00 (minor) and 5.00 (major) is: degree of mechanisation (4.03); format of materials (3.94); details (3.65); specification (3.61), and general design (3.56) [14]. These findings indicate the impact of design on construction ergonomics, and more specifically, the contribution of specification and materials.

2.5. Obstacles to designing for construction ergonomics

The limited availability of ergonomics-in-design tools, guidelines and procedures, and the limited education architects and engineers receive regarding construction ergonomics; constitute obstacles to designing for construction ergonomics [7]. Toole [15] cites, *inter alia*, designers' lack of H&S expertise, and designers' lack of understanding of construction processes as obstacles to designers executing what is necessary to improve worker H&S. This contention is underscored by research conducted in the UK, which investigated *inter alia*, the impact of the CDM Regulations on H&S performance [16]. Two of seven approaches to improve construction H&S through 'H&S by design' related interventions include increasing the risk analysis skills of those involved in design risk assessments, and improving risk assessment techniques.

Designer education and training is widely recognised as being inadequate. In terms of the USA, designers contend that they are not adequately educated or trained to address construction H&S [17]. One essential aspect that has received little attention in the UK is the effective teaching of H&S to construction industry professionals when they are undergoing their tertiary education [18]. Based upon research commissioned by the HSE in the UK, recommendations included, *inter alia*, that academia should rec-

ognise that H&S risk is part of construction risk management and an essential intellectual element of all construction related courses, and all courses / programmes should be audited with a view to including H&S risk management in all built environment programmes as an integral and cross curricula element [19]. Research conducted to investigate the extent to which construction H&S is addressed in tertiary built environment programmes in South Africa, determined that the minority of architectural programmes did [20].

2.6. The impact of handling materials on ergonomics

Three previous self-administered questionnaire based research studies conducted in South Africa investigated, *inter alia*, the frequency at which ergonomic problems are encountered [21; 22; 13]. Handling heavy materials, which achieved an importance index (II) of 2.94 / 4.00 based upon percentage responses to a scale of never to daily, and which is above the midpoint of the II range 0.00 to 4.00, and a ranking of third out of eighteen ergonomics problems in terms of the frequency they are encountered, means that handling heavy materials can be deemed to be encountered between fortnightly to weekly / weekly.

During 1997, materials handling was identified by 78.8% of management respondents and 76.3% of worker respondents as ergonomic aspects requiring attention [21]. The mean percentage response of 77.6% resulted in materials handling being ranked first among nine ergonomic problems requiring attention. During a subsequent study, 92.6% of workers identified materials handling, resulting in it being ranked first out of nine ergonomic aspects requiring attention [22].

2.7. Designer interventions that improve construction ergonomics

The three previously mentioned self-administered questionnaire based research projects conducted in South Africa, investigated, *inter alia*, the potential of various aspects to contribute to an improvement in construction ergonomics. According to general contractors (GCs), designers can contribute to an improvement in construction ergonomics through, *inter alia*, specification of materials (64.0%).

A more recent survey of built environment practitioners surveyed during construction ergonomics seminars also indicated the extent to which various aspects could contribute to an improvement in construction ergonomics. The extent in terms of a mean

score ranging between 1.00 (minor) and 5.00 (major) and based upon percentage responses to scale of 1 (minor) to 5 (major) is: prefabrication (4.31), and specification (4.09) [14].

3. Research

The study was conducted using a survey questionnaire circulated to:

- 100 delegates, which were either architects or architectural technologists, attending a half-day South African Institute of Architectural Technologists (SAIAT) Construction Health & Safety Seminar, 63 of which responded, which equates to a response rate of 63%, and
- 19 delegates, which were also either architects or architectural technologists, attending a one-day South African Institute of Architectural Technologists (SAIAT) Designing for Construction Health & Safety Seminar, 15 of which responded, which equates to a response rate of 79%.

A structured questionnaire was circulated to delegates at the inception of the respective seminars to avert the possibility of delegates' responses being influenced by the contents of the seminars.

Respondents were required to record the mass and density of five and four materials respectively. Table 1 provides a summary of the response per question and the responses within a 10% range of the actual mass or density. The mean response was 75.5% and the non-response was 24.5%. The mean of the percentage responses that were within 10% range of the actual mass or density is 11%, the lowest being 1.5% relative to a two-cell concrete block, and the highest being 23.4% relative to a solid clay brick.

In Table 2 the MS of 2.43 (> 1.80 ≤ 2.60) indicates that the frequency that respondents' practices consider the mass and density of materials when designing and specifying is between never to rarely / rarely.

In terms of the perceived extent to which the mass and density of materials impact on ergonomics, the MS of 3.30 (> 2.60 ≤ 3.40) indicates the impact according to respondents is between near minor to moderate / moderate (Table 3). However, 3.30 is marginally below the immediate upper range, which would mean the impact is between moderate to near major / near major. Therefore, although respondents never to rarely / rarely consider the mass and density

of materials, they do to a degree appreciate the extent to which the mass and density of materials impact on ergonomics.

Table 1

Summary of response and responses within a 10% range of the actual mass or density.

Material	Re-sponse (%)	No response (%)	Responses within range (%)
Solid clay brick	82.1	17.9	23.4
Two-cell concrete block	83.3	16.7	1.5
Precast concrete kerb	83.3	16.7	9.2
Double Roman concrete roof tile	83.3	16.7	10.8
m ² glass 5 mm thick	76.9	23.1	3.4
Concrete	73.1	26.9	19.6
Marble	66.7	33.3	17.3
Sandstone	66.7	33.3	5.8
Steel	64.1	35.9	8.2
Mean	75.5	24.5	11.0

Table 2

Frequency at which practices consider the mass and density of materials when designing and specifying.

Unsure	Response (%)					MS
	Never..... Always					
	1	2	3	4	5	
4.0	24.0	32.0	22.7	9.3	8.0	2.43

Table 3

Extent to which the mass and density of materials impacts on ergonomics.

Unsure	Response (%)					MS
	Minor..... Major					
	1	2	3	4	5	
23.0	8.1	13.5	17.6	23.0	14.9	3.30

In Table 4 the MS of 1.86 (> 1.80 ≤ 2.60) indicates the respondents' rating of their knowledge of the mass and density of materials is between limited to below average / below average. However, 1.86 is just above the upper point of the lower range > 1.00 ≤ 1.80 – between limited to below average.

Table 4

Respondents' rating of their knowledge of the mass and density of materials.

Unsure	Response (%)					MS
	Limited..... Extensive					
	1	2	3	4	5	
4.1	44.6	29.7	14.9	4.1	2.7	1.86

The MS of 3.67 ($> 3.40 \leq 4.20$) indicates the potential of the consideration of the mass and density of materials to contribute to an improvement in construction ergonomics is between moderate to near major / near major (Table 5). As in the case of the respondents' perceived extent to which the mass and density of materials impacts on ergonomics, this is also notable given that the frequency respondents' practices consider the mass and density of materials is between never to rarely / rarely, and the respondents' rating of their knowledge of the mass and density of materials is between limited to below average / below average.

Table 5

Potential of the consideration of the mass and density of materials to contribute to an improvement in construction ergonomics.

Unsure	Response (%)					MS
	Minor.....Major					
	1	2	3	4	5	
13.5	8.1	4.1	18.9	32.4	23.0	3.67

Respondents were requested to provide comments in general regarding the mass and density of materials relative to construction ergonomics. Only 15.7% of respondents had comments in general. The statements can be summarised as follows: there is a lack of awareness; designers lack knowledge; there is a lack of focus; designers do not take ownership of the issue, and tertiary designer built environment education does not address this issue.

4. Conclusions

Given that on average 75.5% of respondents attempted to record a mass or density relative to the materials presented, and that on average, only 11% of the 75.5% were within a 10% range of the actual mass or density, it can be concluded that the respondents are lacking in knowledge relative to the mass and density of materials. This conclusion is reinforced by the respondents' rating of their knowledge of the mass and density of materials, namely 1.86 - between limited to below average / below average. However, as stated, 1.86 is just above the upper point of the lower MS range $> 1.00 \leq 1.80$ - between limited to below average. This lack of knowledge can be concluded to be the likely reason for the frequency at which practices consider the mass and density of materials when designing and specifying, namely between never to rarely / rarely. Therefore, designers

are effectively precluded from conducting optimum design hazard identification and risk assessments.

However, it can be concluded that respondents appreciate the extent to which the mass and density of materials impact on construction ergonomics, as the MS indicates the appreciation to be between moderate to near major / near major, and also the potential of the consideration of the mass and density of materials to contribute to an improvement in construction ergonomics, which potential can be concluded to be between moderate to near major / near major. Despite the aforementioned, tertiary built environment designer education can be deemed to not enlighten designers relative to construction ergonomics

A further conclusion is that the respondents are unlikely to consider the implications of their design and specification in terms of the resultant dead load relative to the permanent structure.

Finally, construction managers, supervisors, and workers cannot expect designers to consider the implications of their design and specification for construction, and more specifically, the mass and density of materials, until such time that the design professions make a paradigm shift and address their lack of knowledge. Furthermore, designers have the potential to contribute to improving the working lives of construction workers through the consideration of the mass and density of materials, either through the elimination of heavy or dense materials or the substituting of them with lighter alternatives.

5. Recommendations

Given that on average 75.5% of respondents attempted to record a mass or density relative to the materials presented, and that on average, only 11% of the 75.5% were within a 10% range of the actual mass or density, the frequency at which practices consider the mass and density of materials when designing and specifying, and the respondents' rating of their knowledge of the mass and density of materials, the design disciplines in the form of the respective councils and professional associations should raise the level of awareness relative to construction ergonomics, evolve related practice notes, and ensure that tertiary built environment designer education addresses construction ergonomics and health and safety (H&S). Such education should address, inter alia, the mass and density of materials, and the role of handling materials in the onset of musculoskeletal injuries. Furthermore, design practices should include

a category 'mass and density of materials' in their practice libraries.

However, in the interim and subsequent to the necessary interventions and actions by the respective councils, professional associations, and tertiary built environment educational institutions, project managers and designers should focus on the mass and density of materials during constructability reviews. During design coordination meetings, architectural and related designers should be sensitised by project managers and engineering designers.

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