Assessment and Mitigation of Ergonomic Factors in Building Construction

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Abstract— Nowadays, the costs of Musculoskeletal Disorders(MSD) are considered as the main proportion of workers compensation related costs in construction industry. Many construction industry sectors have been experiencing chronic problems, such as poor management of workforce, improper working conditions, tools, and working methods. Many researchers have identified these problems as factors that affect construction productivity and overall ergonomic performance of the workers. Keeping in view the necessity of addressing problems as stated, a questionnaire-based survey will be conducted to study the critical issues related to the workers. This research has identified influence ranks of about 30 factors affecting construction ergonomic performance. These factors were classified under the following three primary classifications: a) human/labor related factors; b) tasks-related factors; and c)equipment/tools-related factors based on various age groups and occupations of the construction workers. With the help of RII(Relative Importance Index ranking, critical factors are determined. Then for these critical factors, postural analysis has been done by most effective tool REBA. Industry practitioners and researchers can use the primary outcomes of this study in developing systems to enhance and improve health and safety of the construction workers for effective management of construction labor workforce and to achieve a competitive level of quality and a cost-effective project. The objective of this is to provide an overview of ergonomic exposures in building construction work to assess and understand the level of ergonomics awareness particularly in construction industry and to identify current safety practices associated with the prevention of ergonomic injuries and illnesses in the construction field.

Key words: RII, REBA, Ergonomics, Ergonomics risk factor, Musculoskeletal disorders (MSD)

I. INTRODUCTION

The construction industry is a risky occupation. From generation to generation there is a little improvement in the condition of the industry. Construction industry have highest rate of fatalities as compared to other industries. Thus the major issue of construction industry is safety. The construction industry is far behind with reference to safety Systems in other industries. The injuries and fatalities costs much to the contractor and ultimately to the nation's economy by way of time loss, cost of compensations to workers and loss in productivity. In addition , there is addition to human sufferings and pain due to loss or injury of a dear one for his family and friends. The nature of construction projects itself has potential hazards of accidents since its uniqueness, open space, exposure to weather, involving many unskilled labors, tight schedule of project duration, workers turnover and working at height in confine spaces and psychologically and physically vulnerable working environment. Thus there is a need for awareness among workers working at dangerous places and conditions.

The dynamic nature of this industry has the ability to change on daily basis & hence certain means are required to have reliable tools to measure safety at construction site. It is observed that many factors are responsible for the occurrence of accidents, fatalities & injuries at construction sites. To achieve this goal, the study was conducted to examine numerous factors that should be synthesized in a better way. Nowadays, ergonomic program is considered as one of the effective plan taken into account by many employers to bring safety and health factors for the work environment to maximize work performances. It is a significant principle, since the overall system can be influenced by existing stress on the workers and/or employees body due to inappropriate posture, extremely high or low temperature. Injuries caused by ergonomic risk factor known as ergonomic injuries can also affect cost of the projects due to loss of time, treatment and compensation claims. Compensation claims returns to injury related costs incurred to workers which can be mitigated by applying effective ergonomics program. Ergonomics also brings benefits through the savings associated with low employee turnover, absenteeism.

Ergonomic advantages	**Reducing discomforts**	by reducing the ergonomic risk factors
	Increasing productivity	by providing job satisfaction for workers
	Reducing absenteeism	by making workers to be more engaged and productive by feeling more health and pain-free
	Cost & time savings	by Minimizing injuries Improving productivity of employees Reducing workers' compensation claims
	Increasing morale	by making employees pleasant & feel valued due to safer work environment

Table 1: Advantages of Ergonomics

Industries increasingly require higher production rates and advances in technology to remain competitive and stay in business. As a result, jobs today can involve:

- Frequent lifting, carrying, and pushing or pulling loads without help from other workers or devices;
- Increasing specialization that requires the worker to perform only one function or movement for a long period of time or day after day;
- Working more than 8 hours a day;
- Working at a quicker pace of work, such as faster assembly line speeds; and
- Having tighter grips when using tools

Rapid Entire Body Assessment provides a quick and easy measure to assess a variety of working postures for risk of WMSDs. It divides the body into sections to be coded independently, according to movement planes and offers a scoring system for muscle activity throughout the entire body, stagnantly, dynamically, fast changing or in an

unsteady way and where manual handling may happen which is referred to as a coupling score as it is significant in the loads handling but may not always be using the hands. REBA also gives an action level with a sign of importance and requires minor equipment: Pen and paper method.

Rapid Upper Limb Assessment tool considers biomechanical and postural load requirements of job tasks/demands on the neck , trunk & upper extremities.

II. PROBLEM STATEMENT

The rising numbers of construction sites & there by increase in the number of accidents and ergonomic issues to the labors at construction site makes a critical issue & calls for a serious concern and permanent disability to labors. To find a practical problem it is felt to conduct a study by taking questionnaire interview of various age groups and occupations of the construction workers & there by assigning priorities of different factors & sub factors according to their importance & determining out which factor ranks over the others, there by finding solution. This research has identified the quantified Relative Importance Index (RIIs), determined the influence ranks of 30 factors affecting construction ergonomic performance.

The various objectives of the study are as follows:-

1) To study labor safety for identification of factors affecting to the safety at building construction and finding out ergonomic issues and injuries come up due to faulty postures during work.
2) To study factors in construction safety i.e. Safety skill, Safety Attitude, Safety practices & other factors causing discomfort and ergonomic issues at site.
3) To analyze collected data by using Analytical Hierarchy Process (AHP model) and Relative Importance Index (RII) , Rapid Entire Body Assessment (REBA) & compare the results.
4) Giving recommendations and simple solutions for ergonomic issues to enhance construction safety.

III. STUDY METHODOLOGY

The rising numbers of construction sites & there by increase in the number of accidents and ergonomic issues to the labors at construction site makes a critical issue & calls for a serious concern and permanent disability to labors. To find a practical problem it is felt to conduct a study by taking questionnaire interview of various age groups and occupations of the construction workers & there by assigning priorities of different factors & sub factors according to their importance & determining out which factor ranks over the others, there by finding solution. The two steps followed are as below in table

	Who	Objective	Method	Output
Part1	Workers	Identify which civil activity/factor is causing more discomfort during work	RII	Activity / Factors causing major discomfort to be improved
Part2	Workers & Engineers	Access root &focal area for discomfort & plan improvements	REBA	To measure effectiveness before & after ergonomic change

Table 2:

The output from step 1 is taken for deep engineering analysis for solutions.

Part 1: - This research has identified the quantified Relative Importance Index (RIIs), determined the influence ranks of 30 factors affecting construction ergonomic performance .In this study, we analyze about impact of he entire study was carried out from identification of problem up to the result and discussion for the problem. To improve construction ergonomic performance, it is essential to identify and recognize the influence of the primary factors affecting ergonomic performance of the construction workers leading to a number of musculoskeletal disorders.

The perceived effect of each of the 30 factors is determined. The overall factors are classified under three major categories viz.

a) Human/labor related factors;
b) Tasks-related factors; and
c) Equipment/tools-related factors

Based on various occupations of the construction workers.

Human related factors	**Level of discomfort in joints**	**Level of discomfort in joints**
	Neck	**Bending**
	Shoulder	**Squatting**
	Elbow	**Standing**
	Wrist	**Stretching**
	Knuckle	**Sudden changing position**
	spine	**Twisting**
		Kneeling
		stooping

Table 4:

Task related factors	**Equipment/tools related factor**
Methods of work	**Tools / equipment**
Work load	**Equipment heavy to handle**
Repetitive work	**Difficulty in grasping**
Lack of rest	**Accident while using hand tool**
Climate/environment	**PPE create difficulty/obstruction**
Awkward posture	
Static posture	
Physically tired	
Overall discomfort level(after 2 hrs)	

Table 5:

Keeping in view the necessity of addressing problems as stated, a questionnaire-based survey was conducted and primary data for ergonomic design and analysis were collected from a construction site of residential building/ apartment and searched issues related to the workers. Data were collected through the survey are required for identifying and properly assessing the risk factors associated with various ergonomics are necessary.

Furthermore, based on the responses, the contribution of each of the factor influencing construction ergonomic performance were examined and the ranking of the attributes in terms of their criticality as perceived by the respondents was found by Relative Importance Index (RII) which is as follows:

$$RII = \frac{\text{Sum}(W)}{A * N} \quad (0 < RII < 1)$$

where, W = Weight given to each factor by the respondents
A = Highest weight
N = Total number of respondents..

Part II Rapid Entire Body Assessment (REBA) Consider critical tasks of a job. For each task, assess the posture factors by assigning a score to each region. Score the Group a (Trunk, Neck and Legs) postures and the Group

B (Upper Arms, Lower Arms, and Wrists) postures for left and right. For each region, there is a posture scoring scale plus adjustment notes for additional considerations. Then score the Load / Force and Coupling factors. Finally, score the Activity Find the scores from Table A for the Group A posture scores and from Table B for the Group B posture scores. The tables follow the data collection sheet.

Score A is the sum of the Table A score and the Load / Force score. Score B is the sum of the Table B score and the Coupling score for each hand. Score C is read from Table C, by entering it with the Score A and the Score B.
The REBA score is the sum of the Score C and the Activity score.

Score A represents the summation of the posture scores for the trunk, neck and legs and the Load/Force score. Group A has a total of 60 posture combinations for the trunk, neck and legs. This reduces to nine possible scores to which a "Load/Force" score is added.

Score B is the sum of the posture scores for the upper arms, lower arms and wrists and the coupling score for each hand. Group B has a total of 36 posture combinations for the upper arms, lower arms and wrists, reducing to nine possible scores to which a "Coupling" score is added.

The A and B scores are combined in Table C to give a total of 144 possible combinations and finally an activity score is added to give the final REBA score. The Activity score describes any static postures held for longer than 1 minute and a repetition more than 4 times per minute or large rapid changes in postures, or an unstable base.

A. REBA Scoring Sheet (I)

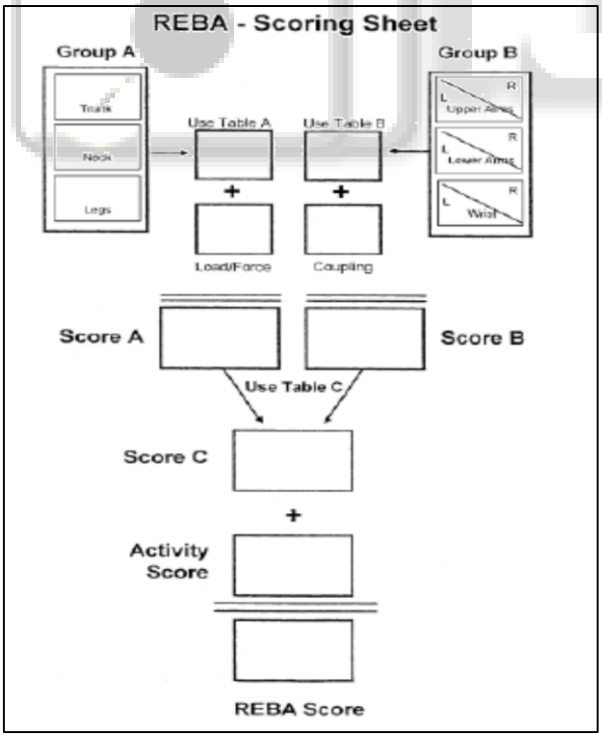

Fig. 1: REBA Scoring Sheet (I)

B. REBA Scoring Sheet (II)

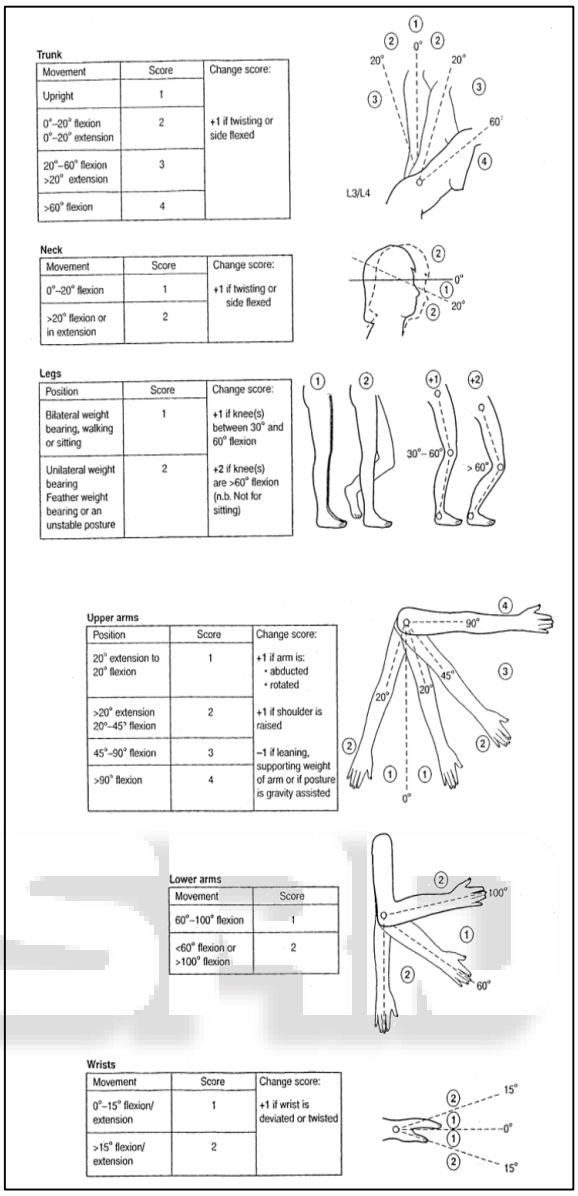

Table 6:

A specific process is used considering all these factors and a REBA score is produced, as a number between 1 and 15. This REBA score represents REBA action level (between 0 and 4) defining whether action is required and its urgency. The process sometimes can be repeated when changing the task due to interventions or control measures, the new REBA score can be compared with the previous one to monitor the effectiveness of the changes.

REBA SCORE	RISK LEVEL
1	Negligible
2-3	Low
4-7	Medium
8-10	High
11-15	Very High

Rapid Entire Body Assessment (REBA) Date: / /

Task	Analyst

Group A			Group B			
Posture/Range	**Score**	**Total**	**Posture/Range**	**Score**	**Total: Left and Right**	
Trunk			**Upper Arms (Shoulders)**		L	R
Upright	1	If back is twisted or tilted to side: +1	Flexion: 0-20° Extension: 0-20°	1	Arm Abducted / Rotated: +1	
Flexion: 0-20° Extension: 0-20°	2		Flexion: 20-45° Extension: >20°	2		
Flexion: 20-60° Extension: >20°	3		Flexion: 45-90°	3	Shoulder Raised: +1	
Flexion: >60°	4		Flexion: >90°	4	Arm Supported: -1	
Neck			**Lower Arms (Elbows)**		L	R
Flexion: 0-20°	1	If neck is twisted or tilted to side: +1	Flexion: 60-100°	1	No Adjustments	
Flexion: >20° Extension: >20°	2		Flexion: <60° Flexion: >100°	2		
Legs			**Wrists**		L	R
Bilateral Wt Bearing; Walk; Sit	1	Knee(s) Flexion 30-60°: +1	Flexion: 0-15° Extension: 0-15°	1	Wrist Deviated / Twisted: +1	
Unilateral Wt Bearing; Unstable	2	Knee(s) Flexion >60°: +2	Flexion: >15° Extension: >15°	2		
Score from Table A			**Score from Table B**		L	R
Load / Force			**Coupling**		L	R
< 5 kg < 11 lb	0	Shock or Rapid Buildup: +1	Good	0	No Adjustments	
5 - 10 kg 11 - 22 lb	1		Fair	1		
> 10 kg > 22 lb	2		Poor	2		
Score A [Table A + Load/Force Score]			Unacceptable	3	Left	Right
Activity			**Score B** [Table B + Coupling Score]		L	R
One or more body parts are static for longer than 1 minute		+1	**Score C** (from Table C)		L	R
Repeat small range motions, more than 4 per minute		+1	**Activity Score**		L	R
Rapid large changes in posture or unstable base		+1	**REBA Score** [Score C + Activity Score]		L	R

Table 7: REBA Score Table

Table A		Trunk				
		1	2	3	4	5
Neck = 1	Legs					
	1	1	2	2	3	4
	2	2	3	4	5	6
	3	3	4	5	6	7
	4	4	5	6	7	8
Neck = 2	Legs					
	1	1	3	4	5	6
	2	2	4	5	6	7
	3	3	5	6	7	8
	4	4	6	7	8	9
Neck = 3	Legs					
	1	3	4	5	6	7
	2	3	5	6	7	8
	3	5	6	7	8	9
	4	6	7	8	9	9

Table B		Upper Arm					
		1	2	3	4	5	6
Lower Arm = 1	Wrist						
	1	1	1	3	4	6	7
	2	2	2	4	5	7	8
	3	2	3	5	5	8	8
Lower Arm = 2	Wrist						
	1	1	2	4	5	7	8
	2	2	3	5	6	8	9
	3	3	4	5	7	8	9

Table C		Score A											
		1	2	3	4	5	6	7	8	9	10	11	12
Score B	1	1	1	2	3	4	6	7	8	9	10	11	12
	2	1	2	3	4	4	6	7	8	9	10	11	12
	3	1	2	3	4	4	6	7	8	9	10	11	12
	4	2	3	3	4	5	7	8	9	10	11	11	12
	5	3	4	4	5	6	8	9	10	10	11	12	12
	6	3	4	5	6	7	8	9	10	10	11	12	12
	7	4	5	6	7	8	9	9	10	11	11	12	12
	8	5	6	7	8	8	9	10	10	11	12	12	12
	9	6	6	7	8	9	10	10	10	11	12	12	12
	10	7	7	8	9	9	10	11	11	12	12	12	12
	11	7	7	8	9	9	10	11	11	12	12	12	12
	12	7	8	8	9	9	10	11	11	12	12	12	12

Table 8: REBA Scoring Reference Tables A, B, C

IV. DATA ANALYSIS

This study presents the results of a systematically collected data through construction sites of shela area in Ahmadabad city & it is hope that it will contribute to many areas of construction industries throughout the states and country.
The workers were asked questions related to type of work, total working hours, and level of discomfort in various body joints and body movements. The ergonomic issues which they are facing related to their work and asked to assign scores low, medium and high i.e. 1, 2, 3.

For analysis purpose, data pertinent to the characteristics of tasks, features of the working environment, types of MMH activities and their characteristics, of the jobs/tasks, and types of tools and equipment used are collected from a sample of 90 construction workers out of which 19 are skilled, 27 are semiskilled helpers and 44 are unskilled . In all the occupations considered, there are female workers only working as a unskilled as they are around 33% of total number of population. It is found that 48 % of the Skilled and 26 % Semiskilled are between the age group of 25-34 years and 8 % are less than 25 years. Depending on the criticality of their work, the workers work around more than 8 hours with three to four hours of overtime in both (open and closed) environments.

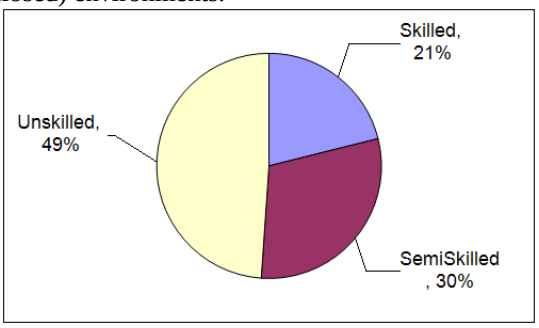

Fig. 2: Skill Pie chart

Relative Importance Index (RII) was calculated for each of the factors so that the important and critical factors may be identified and proper preventive and remedial measures could be taken up.

A. Factor A) Level of discomfort in body joints and RII

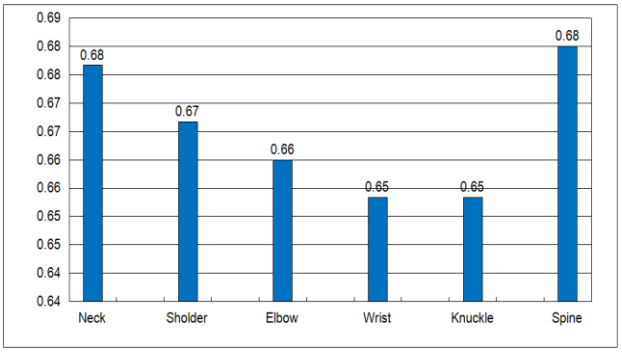

Fig. 3: Discomfort in body joints (Including Skilled, Semiskilled & Unskilled)

Level of discomfort on various body joints on X-axis and relative importance index (RII) on Y-axis. The above graph shows that there is high level of discomfort in neck joint. And also less level of discomfort in knuckle.

Sr No	Human/labor related factors	Skilled		Semi Skilled		Unskilled	
	(Level of Discomfort in Various Body Joints)	RII	Rank	RII	Rank	RII	Rank
1	Neck	0.71	2	0.68	2	0.64	5
2	Shoulder	0.66	4	0.67	3	0.67	3
3	Elbow	0.68	3	0.64	4	0.66	4
4	Wrist	0.73	1	0.62	5	0.61	6
5	Knuckle	0.65	5	0.59	6	0.72	1
6	Spine	0.62	6	0.73	1	0.69	2

Table 9: RII and its ranking wrt to body joints

B. Factor B) Level of discomfort in various Body movements & RII

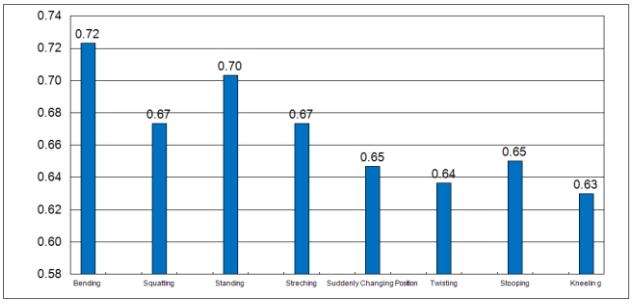

Fig. 4: Discomfort in body movements (Including Skilled, Semiskilled & Unskilled)

Level of discomfort on various body movements on X-axis and relative importance index (RII) on Y-axis. The graph shows high level of discomfort in bending position & RII Value.

Table 10: RII and its ranking

Sr No		Skilled		Semi Skilled		Unskilled	
	(Level of Discomfort in Various Body Movements)	RII	Rank	RII	Rank	RII	Rank
1	Bending	0.71	2	0.73	1	0.73	1
2	Squatting	0.66	5	0.68	3	0.68	3
3	Standing	0.73	1	0.69	2	0.69	2
4	Stretching	0.69	3	0.69	2	0.64	5
5	Suddenly Changing Position	0.63	7	0.67	4	0.64	5
6	Twisting	0.62	8	0.66	5	0.63	6
7	Stooping	0.65	6	0.64	6	0.66	4
8	Kneeling	0.67	4	0.61	7	0.61	7

wrt to body movements

C. Factor c) Level of Discomfort in methods of work

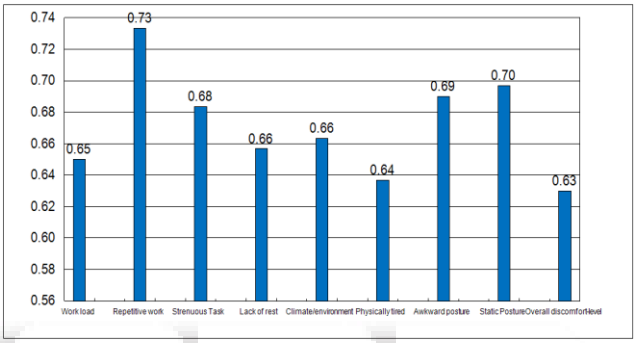

Fig. 5: Discomfort in methods of work(Including Skilled , Semiskilled & Unskilled)

Sr No		Skilled		Semi Skilled		Unskilled	
	(Level of Discomfort in Various Methods of work)	RII	Rank	RII	Rank	RII	Rank
1	Work load	0.69	3	0.6	8	0.7	6
2	Repetitive work	0.74	1	0.72	2	0.7	1
3	Strenuous Task	0.6	8	0.74	1	0.7	3
4	Lack of rest	0.61	7	0.71	3	0.7	7
5	Climate/environment	0.63	6	0.64	5	0.7	2
6	Physically tired	0.65	5	0.62	6	0.6	8
7	Awkward posture	0.71	2	0.69	4	0.7	5
8	Static Posture	0.69	3	0.71	3	0.7	4
9	Overall discomfort-level	0.67	4	0.61	7	0.6	9

Table 11: RII and its ranking wrt to methods of work

D. Factor d) Level of Discomfort in equipment/tools related category Graph Discomfort in equipment /tools related category (Skilled , Semiskilled & Unskilled)

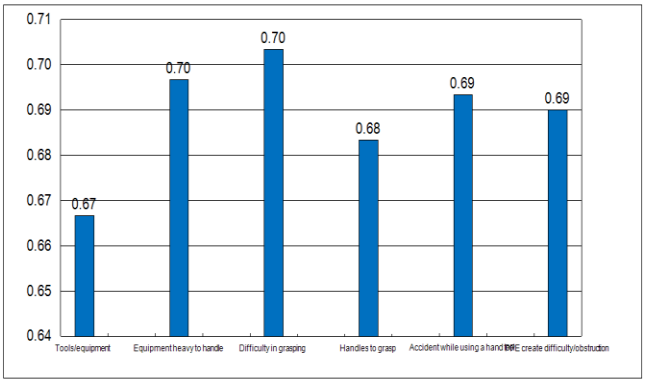

Fig. 6: RII Equipment and tools related category

Sr No		Skilled		Semi Skilled		Unskilled	
	(Level of Discomfort in equipment/Tools related category)	RII	Rank	RII	Rank	RII	Rank
1	Tools/equipment	0.76	1	0.63	6	0.61	6
2	Equipment heavy to handle	0.7	5	0.7	3	0.69	2
3	Difficulty in grasping	0.72	3	0.72	2	0.67	3
4	Handles to grasp	0.73	2	0.66	5	0.66	4
5	Accident while using a hand tool	0.67	6	0.68	4	0.73	1
6	PPE create difficulty/obstruction	0.69	4	0.75	1	0.63	5

Table 12: RII and its ranking wrt to equipment and tools related category

II] REBA Method: = One Improvement Example Below

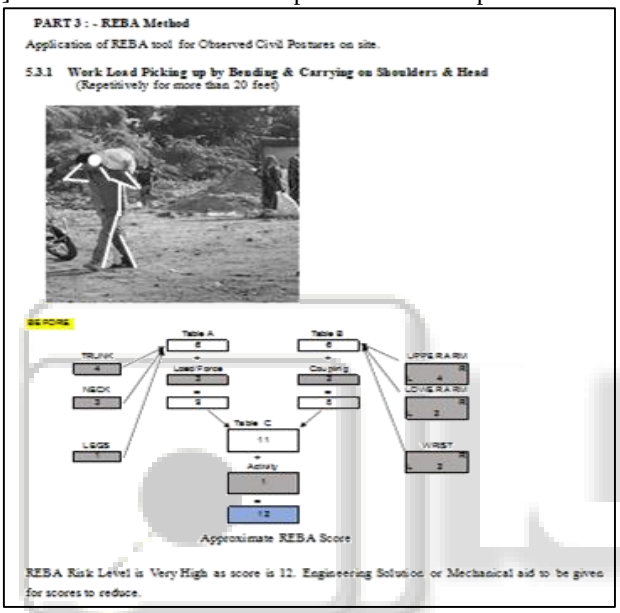

Fig. 7:

These solutions are simple to implement & economical also will greatly reduce the MSD which generally found in civil workmen.

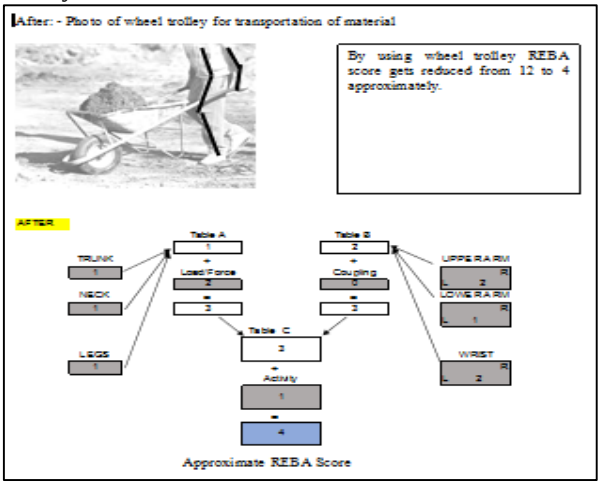

Fig. 8:

The use of wheel trolley has significantly reduced the REBA score from 12 to 4. The Risk associated post improvement is very much acceptable. Such cost effective solutions & easy to implement are most welcomed by the management & workmen also.

V. Results & Discussion

Relative Importance Index (RII) was calculated for each of the factors so that the important and critical factors can be identified and proper preventive and remedial measures could be taken up. These various factors were ranked by using RII method. Then critical factors were solved using REBA methodology to improve ergonomic condition at work place. These simple economical solutions will result into reduction of Ergo issues at construction site which will help to improve productivity & morale of the working level people.

VI. Guidelines and Recommendations

Finally, in a broader context, by increasing the knowledge and awareness of ergonomics, and training members to recognize the ergonomic risk factors in the work environment, this will lead to increasing of productivity, safety and health of employees in the construction industries. As each construction occupation and task represents a unique situation, identification and application of preventive measures, tools and proper work conditions may be best derived from occupations and task-specific MMH studies. It is crucial and important to mention that ergonomic interventions are required to be implemented on a priority basis for maintaining the work ability among workers and minimize the incidence of injuries and accidents in various construction occupations

Type of Labor	Activity	Body Part	Solution
Skilled	Reinforcing	Repetitive, fast movements of wrist, bending	Use of rebar tying tool
	Masonry	Strong stress on back, shoulder	Designing tools which involve hand-holds to facilitate and develop lifting bricks
	Concreting	Back pain, stress on soft tissues	Regular breaks and providing additional suitable tools such as plasticizers reduce repetitive works and increase efficiency.
Semiskilled	Plastering	Stress on wrist and neck	Regular breaks, reach to working height as far as possible
	Cutting pipes/tiles	Squatting, Kneeling	Providing tripod benches reduces stress
	Tiling	Kneeling, bending	Change of process & tools
Unskilled	Load carrying	Neck/Shoulder	Use of PPE , Lifting Devices

Table 13:

VII. Conclusions

This study concludes the result of the survey conducted related to safety especially of construction ergonomic performances and issues and injuries come up due to faulty posture. According to the results the following conclusions are made for construction companies

1) Nature of work, different ergonomic factors, fatalities, hazards & innovations are very important but not identified by the respondents on their own.
2) This study shows the important and unique factors affecting to ergonomics which ultimately gives result in health and safety of workers and project success.

3) By comparing RII of different ergonomic factors, critical factor has been determined.
4) Well trained professionals & experts are needed for enhancing the safety status of civil industry.
5) Many low cost solutions can be benchmarked from other industries and implemented easily to reduce the ergonomic factors which will enhance moral of the labors.
6) By attempting the members of safety committee and information shared in safety meetings, common risk factors can be identified easier and suggestion will be made available to employees to avoid injury and work in a more efficient manner.
7) Recommendations and guidelines has been suggested for safe working environment.

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