Chapter 30
Ergonomic Assessment of Collecting, Lifting, Throwing and Receiving Postures' of Indian Excavation Workers Using CATIA

Manoj T. Gajbhiye, Debamalya Banerjee, and Saurav Nandi

Abstract Manual evaluation of dynamic working posture and loads on the different body parts is impossible owing to the continuous movement of the body and compact workplace. Such kind of dynamic working postures and loads are being evaluated by computer software. This study aimed to evaluate five postures performing different tasks of excavation work using computer software (CATIA) by developing a computer manikin, thereafter analysing the posture of the manikin and loads on the manikin. Manikin's of the five postures were modelled in the CATIA software subsequently RULA, biomechanical and lifting analysis was performed on the five postures. RULA score revealed that all working postures are found at very high ergonomic risk. The biomechanical result revealed that compression load on L4/L5 was found more in the task of receiving of the iron pan by the outside worker (Task-4), throwing of soil (Task-3 and Task-5) and lifting of the iron pan (Task-2) which found to be higher than the recommended limit of NIOSH. A remedial solution is required to minimize this problem by developing a tool or changing the work method.

Keywords Ergonomics · Excavation · RULA · Biomechanical · Lifting · CATIA

Introduction

Mainly, awkward posture is the body position; when the body, while executing a working task does not work in the neutral position due to which muscles get stressed. This non-neutral working posture leads to work-related musculoskeletal disorders (WRMSD). High biomechanical force on numerous physically demanding tasks includes heavy lifting, repetitive motion, inadequate rest time, forceful physical exertion and working in an awkward posture for a prolonged period which leads

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to the development of work-related musculoskeletal disorder [1, 2]. This problem nowadays became very common while working in an awkward posture, working with hands above the shoulders, repetition of work, frequent lifting and lowering, prolonged standing or sitting in the awkward postures without support at work site [3].

Excavation of soil (digging), collection of excavated soil in the iron/head pan, lifting of the iron/head pan, throwing of excavated soil outside the pit or passing of the iron pan to the worker standing outside the column pit are the main task of excavation work. When the depth of the pit goes deep and the worker is unable to throw the excavated soil out of the pit, an additional worker is required. All digging works are dynamic and require high physical effort for excavation and lifting work.

In India, this pernicious, powerful and dynamic task is performed manually by men and women. For the execution of work, workers use pickaxe, iron pan and hoe for collection of excavated soil. The worker himself lifts the iron pan from the ground to throw the excavated soil as well as to give it to the worker standing outside near the surface of the column pit. The usual size of the column pit is $5' \times 5' \times 6'$. This column pit takes three to four days to extricate which depends upon the nature of the topsoil. In most places, a problem arises when soil is moist that takes more time to excavate.

Assessment of such dynamic, forceful and repetitive work is not possible manually and require computer intervention. In this paper, computer-aided three-dimensional interactive application (CATIA) is used which is human simulation software that confirms the three-dimensional (3D) model of body postures details analysis. CATIA is capable of providing different ergonomic analysis that widely comprises all aspect of machine and human. Many old methods have also been upgraded as per requirement and for better results [4, 5]. CATIA is used in many other works for the assessment of posture and shows better result [6–8]. CATIA provides a perfect evaluation of stresses on different body parts in the practical scenario. It includes an assessment of RULA, lifting/lowering/pushing/pulling/carry analysis and biomechanical single action analysis [9].

The literature revealed that research work is being carried out in many occupational activities of the construction work; however, no work has been yet carried out that highlighted the issue related to manual excavation. Therefore, this paper aims to evaluate postures of five tasks performed by the excavation workers by modelling the manikin of these postures in CATIA and thereafter perform RULA, lifting and biomechanical analysis of load on the vertebral column of L4/L5.

Materials and Methods

A two-week study carried was out at different construction sites, and 42 males were video recorded, observed and interviewed engaged in the excavation of the column pit. The workers' data, feeling of pain as well as the weight of the empty and filled iron pan, pickaxe and hoe weight were weigh, noted down and discussed. A simple questionnaire exercised consisting of individual information, a task carried out, WRMSD symptoms, feeling of discomfort in the different body parts, traumatic incidents history and present lifestyle. CATIA V5 software was used to develop and analyse the computer manikin of the selected real-time image which were at high risk. The real-time image of manikin modelled in CATIA for the tasks (1) collection of soil in an iron/head pan (Task-1), (2) lifting of the iron pan from the ground (Task-2), (3) throwing the soil outside the pit or passing iron pan to the outside worker (Task-3), (4) receiving of the iron pan by the outside worker (Task-4) and (5) throwing of soil by the outside worker (Task-5). RULA, biomechanical and lifting analysis were carried out.

Results

The studied workers engaged in manual excavation work at building construction sites. Table 30.1 shows the workers' age (years), height (cm), weight (kg), experience (years), BMI (kg/m^2), working hours and rest hour. Duration of working hours depends upon the requirement of work demand but the standard working hours per day is 8 (±2 h) with rest 1(±30 min). The responses to pain in body parts and percentage are represented in Table 30.2 and Fig. 30.1. The workers' complained about discomfort in the lower back (83.33%) followed by the shoulders (83.33%), arms/hands (73.81%), wrists (40.48%), fingers/thumbs (30.95%), legs (26.19%), chest (21.43%), head (16.67%) and neck (7.14%). From video observation, it observed that 83.33% or more workers were working in awkward postures. Breathing problem was faced deep inside the column pit; they faced the problem of breathing.

Excavating workers performed Task-1, Task-2 and Task-3, and outside worker performed Task-4 and Task-5. Figure 30.2a–e shows the real-time images of excavation work and the task considered for analysis. The RULA, biomechanical and lifting analysis were carried out on the computer manikin by considering working postures, repetition, static muscle load, force and break time while developing computer

Table 30.1 Somatic characteristics of workers

Characters	Mean (±SD)
Age (years)	40.69 (±9.39)
Height (cm)	162.43 (±5.26)
Weight (kg)	61.11 (±5.72)
Work Experience (years)	17.48 (±9.55)
BMI (kg/m^2)	23.16 (±1.84)
Working hours/day (h)	8 (±1)
Rest hours/day (h)	1 (±30 min)

Table 30.2 Worker reply to pain/discomfort

Body parts	No. of workers	Percentage of workers
Head	7	16.67
Neck	3	7.14
Shoulder	35	83.33
Chest	9	21.43
Arms/hands	31	73.81
Wrist	17	40.48
Finger/thumbs	13	30.95
Lower back	35	83.33
Legs	11	26.19

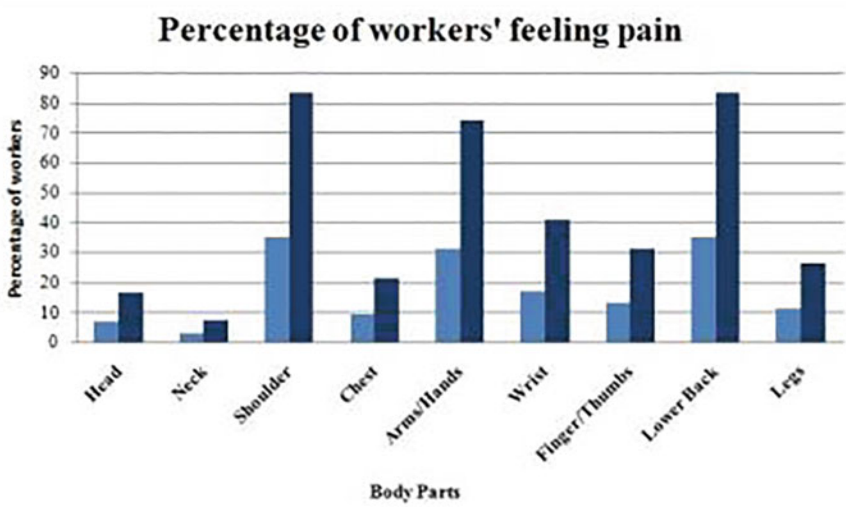


Fig. 30.1 Percentage of workers' feeling pain

manikin. The standard rule of anthropometry has set as per the rules. Green, yellow, orange and red colours have been assigned for "acceptable posture", "need further investigation and change", "need further investigation and change soon" and "need investigation and change immediately", respectively [10].

(a) Real time image of collection of soil in pan

(b) Real time image of lifting of pan from ground level

(c) Throwing of excavated soil or passing pan to outside worker

(d) Receiving of pan by outside worker from inside worker

(e) Throwing of soil by worker standing outside the pit

Fig. 30.2 Real-time images

Working Postures for Different Tasks

Collection of Soil in an Iron/Head Pan (Task-1)

During this task, the trunk of the worker remains in the flexion position at the lumbar (more than 90°); both arms below shoulder level while the wrist under ulnar deviation. Legs are at abducted position at thighs and in flexion position in between 30° and 60° at knees position (Fig. 30.2a).

Lifting of the Iron Pan from the Ground Level (Task-2)

In this task, the worker used to bend forward (flexion) at the lumbar with more than 90° with arms below shoulder level. The workers sometimes work in the twisted posture at the trunk. Trunk, neck and wrist are in extension position for more than 45°. The worker holds the iron pan at elbow height, then at shoulder height and then overhead and the entire weight of the pan enforces on the workers' hands. Both legs are in an abducted position from thighs and flexion position at the knee position (>60°) (Fig. 30.2b).

Throwing of the Soil Outside the Pit or Passing Iron Pan to the Outside Worker (Task-3)

While doing this, the vertebra of the worker is in the extension position. Hands are above the shoulders height lifting the pan, extended and abducted at shoulders. The neck is also in the extension position while the legs abducted at the thighs and flexion at the knees (Fig. 30.2c).

Receiving of the Iron Pan by the Outside Worker (Task-4)

In this task, the worker bends forward (flexion-about 60° to 90°) with a rotation of the full spine more than 20°. The vertebra and neck are found in the extension position while arms in perpendicular at shoulders. Arms are above shoulder level after picking the iron pan for throwing excavated soil. The worker's right leg is at the plain surface with flexion (30°–60°) slightly. The left leg is above the dumps soil with flexion position (>60°). The right leg is slightly abducted at the thigh with flexion at the knee, while the left leg is abducted at the thigh at an angle of 30°, whereas bending (flexion) 90° at the knee position (Fig. 30.2d).

Throwing of Soil by Outside Worker (Task-5)

The position of this task is shown in Fig. 30.2e. The outside worker is standing at an uneven surface (created due to dumping of soil) with one leg at the plain surface while the other above the uneven surface. In this position, the right leg of the worker is straight in position while the left leg is flexion and abducted at the thigh and flexion at the knees position. Hands are above shoulders level holding iron pan, and wrists are in the extension position.

RULA Analysis

The RULA scores are observed with work repetitions, static load on muscle load, awkward working postures and no rest time. Table 30.3 shows the final RULA score for all five tasks. For all the tasks, RULA scores obtained are higher than 7, so it was revealed that investigation and immediate change are required. The RULA score shows that the neck, trunk and legs are mainly affected while collecting soil, lifting iron pan and receiving iron pan. It often affects the wrists and hands when throwing out excavated soil or handing out iron pans to outside workers. The scores are more for wrists/arms and neck/trunk/legs. RULA score shows that neck, trunk mainly lumbar portion and legs are mostly affected due to working in awkward postures.

Table 30.3 RULA score for all five tasks

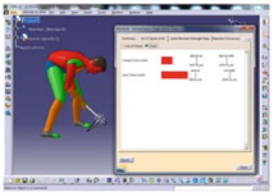
	Task 1	Task 2	Task 3	Task 4	Task 5
Wrist/arms	5	4	7	6	7
M	1	1	1	1	1
F	2	3	3	3	3
PS-A	8	8	11	10	11
Neck/trunk/legs	8	7	5	8	6
M	1	1	1	1	1
F	2	3	3	3	3
PS-B	11	11	9	12	10
RULA SCORE	>7 (VHR)	>7 (VHR)	>7 (VHR)	>7 (VHR)	>7 (VHR)

Biomechanical Analysis

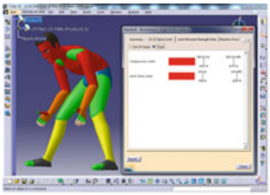
The biomechanical analysis calculates and provides information about lumbar spinal loads like moments, compression, shear force, abdominal force and abdominal pressure. All outputs of the designed model are based on the scientific research data. Table 30.4 and Fig. 30.3a–e show the results of biomechanical single action analysis. Table 30.4 shows the detailed summary of biomechanical analysis results for all five tasks for all five postures. The maximum lumbar torque at L4/L5 is found as 75 Nm, 156 Nm, −28 Nm, 260 Nm and 116 Nm; compression at L4/L5 is found as 1063 N, 2587 N, 1032 N, 5719 N and 3530 N; and Joint shear load at L4/L5 is found as 385 N, 379 N, 50 N, 202 N and 109 N for Task-1, Task-2, Task-3, Task-4 and Task-5. The compression of L4/L5 is found more in Task-4 (5719 N) and Task-5 (3530 N) above the maximum allowable compression force of 3400 N. The joint shear load is found more for Task-1 (385 N), Task-2 (379 N) and Task-4 (202 N). The abdominal force and abdominal pressure are found to be 183 N, 75 N and 48 N and 6 N/m^2, 3 N/m^2 and 2 N/m^2 on Task-4, Task-2 and Task-1.

Table 30.4 Biomechanical analysis result of all five tasks for all five postures

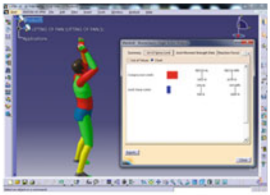
	Task 1	Task 2	Task 3	Task 4	Task 5
L4/L5 moment (Nm)	75	156	−28	260	116
L4/L5 Compression (N)	1063	2587	1032	5719	3530
Body load compression (N)	−351	−49	604	179	606
Axial twit compression (N)	46	25	3	572	30
Flexion/extension compression (N)	1249	2605	335	4336	1938
L4/L5 Joint shear (N)	385 (A)	379 (A)	50 (A)	202 (A)	109 (A)
Abdominal force (N)	48	75	0	183	0
Abdominal pressure (N/m^2)	2	3	0	6	0



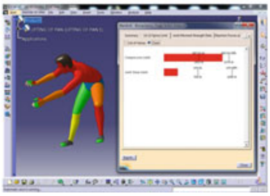
(a) Collection of soil in pan



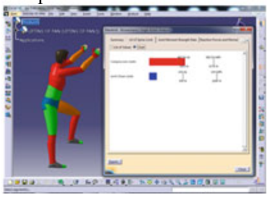
(b) Lifting of pan from ground



(c) Throwing of soil outside the pit or passing of pan to outside worker



(e) Receiving of pan by the outside



(d) Throwing of soil by outside worker

Fig. 30.3 Biomechanical analysis for all five tasks for all five postures

Lifting Analysis

Lifting analysis is carried out to identify the risk of physical stress associated with manual lifting. National Institute for Occupational Safety and Health developed and recommended some standard lifting equations with a recommended weight limit and lifting index [11]. The manikin developed in CATIA V5 was studied to lift of the filled iron pan from the ground level to overhead (Fig. 30.4). Workers fill and lift the pan every after 20–30 s throughout the day, except for the rest period. Since the iron pan is semi-circular and there is no handle to lift the iron pan, the worker have to lift the iron pan from the below. The worker averagely lifts a pan of weight

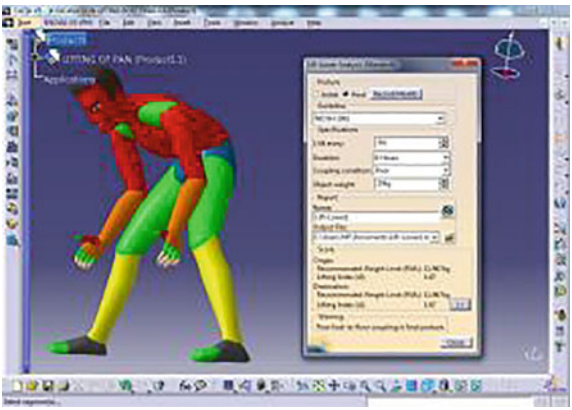


Fig. 30.4 Result of lifting of pan as per NIOSH 1991 guidelines

Table 30.5 Result of lifting pan from ground

Parameters	Values
Recommended weight limit (RWL) (1991)	11.967 kg
Lifting index (LI) (1991)	1.67
Poor foot to foot coupling in final posture	

which ranges from 15 to 20 kg incorporating the weight of the iron pan and the soil. The result revealed that the lifting index (1.67) is more than the recommended level (<1), as well as a foot to foot coupling, is not in the proper position in the posture (Table 30.5).

Discussion

As mentioned above, excavation work includes different tasks of a dynamic nature. In this paper, CATIA was used to assess the posture of five tasks of excavation. Strong stress and intense pressure are applied to the body of the worker while performing different excavation work. Also, the workers worked in awkward postures throughout the day. The RULA scores indicate that the neck, shoulders, arms/hands, lumbar and legs are working at very high risk. The biomechanical analysis of CATIA shows that Task-4 has more compression at L4/L5 which is above the maximum allowable compression force of 3400 N followed by Task-5 and Task-2 [12]. Though the lifting task (Task-2) has shown less compression (2587 N) at L4/L5 of the vertebrae, the joint shear load (379 N) is near to the maximum allowable limit of 500 N; moreover, as the weight increases, this will increase.

The workers are working in a twisting position while throwing the soil (Task-5 and Task-3) and receiving the pan (Task-4). When collecting soil in an iron pan and lifting the pan, workers bend in more than 900 flexion positions which are not acceptable as per rule, and this flexion angle must be reduced by improving the design or collection method of the pan. According to the NIOSH 1991 guidelines, if the lifting score is greater than 1, the lifting technique is incorrect [11, 13, 14]. The results of the CATIA software show that when a worker lifts 15–20 kg weight, it exceeds the recommended weight limit (RWL = 11.687) and (LI = 1.67) [14]. Based on the analytical results obtained from RULA, biomechanical and lifting analysis derived from the CATIA V5 software, excavation workers perform high physical work putting excessive load on the spinal (vertebra) segment L4/L5. Therefore, efforts must be made to reduce this load on the vertebral column of the spinal cord.

Conclusion

In this paper, postures of five tasks of conventional working methods adopted by excavation workers were modelled and evaluated using CATIA software. The result of the conventional working postures shows high compressive and shear loads on the excavated workers L4/L5 which requires intervention to reduce the level of risk on the workers' spinal cord at construction sites. The results of RULA, biomechanical and lifting revealed that the excavation workers' working at high ergonomic risk when working with traditional methods and tools. Working in awkward postures, collection of excavated soil in the conventional iron pan, lifting of the iron pan without proper holding or coupling device, working overhead to throw soil out of the pit or handing pan to the other worker, collecting pan by the outside worker by standing at the poor work surface are some of the causes of WRMSD.

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