Chapter 12
Computational Assessment of Indian Excavation Workers' Posture and Biomechanical Analysis Using CATIA

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1 Introduction

A strong foundation plays a vital role in any construction work. The preliminary work is the erection of a column for the foundation, starting from the ground by excavating the soil crust to the construction of the house. In India, this dynamic, physically exhaustive, forceful and heavy weight-lifting work is carried out manually by both men and women who may be suffering from work-related musculoskeletal disorders (WRMSD).

Excavation is the process of removing soil by excavating the ground to lay down the foundation and erecting the column for construction work. This work is hazardous as well as dynamic in nature, which requires high physical effort and is carried out manually in India. These workers are exposed to different physical and environmental effects and are eventually exposed to work-related musculoskeletal disorders (WRMSD).

In India, excavation work is carried out manually and does not use machinery due to the unavailability of space for machinery, though the technology improved. The size of the column pit is varying as per the requirement, but the standard size of the column pit is 1.22 m × 1.22 m × 1.52 m, which is dug manually with the help of a pick-axe. This column pit takes 3–4 days for excavation by single workers with 8–10 working hours per day. The time of working and time of extraction depends on the type of soil, requirement of work and time to finish the task. During excavation work, the workers have to perform four tasks: (1) Excavation of soil crust with the help of

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pick-axe in which workers have to work with two postures as shown in Figs. 2a and 3a; (2) collection of excavated soil in the iron pan with the help of spade in which workers have to flexed forward >90°; (3) lifting of the iron pan from the ground to shoulder level and overhead and (4) throwing soil outside the pit or passing the iron to the outside worker when working in deep. The excavation work is a dynamic and repetitive work where the workers need to apply high force to loosen the soil and for lifting, throwing the excavated soil or passing the iron pan.

The assessment of such types of dynamic work is not possible without using a computer. Recently, the work processes were video-recorded and their analysis was carried out using computer software. Therefore, in this paper, the evaluation of Indian excavation workers' posture and biomechanical analysis of force/load on the spinal segment of L4/L5 is carried out using CATIA software.

2 Materials and Methods

2.1 Subjects and Data Collection

A total of 42 male workers were observed, interviewed and recorded from 16 different construction sites. Verbal permission from house owners, contractors and workers was sought first. The workers' data, pain or discomfort in body parts and other related problems were discussed and noted down.

A two-week study is carried out by visiting different construction sites. For collecting data, a simple questionnaire was framed, which consists of personal information, type of work activities, symptoms of WRMSD, other history of traumatic incidents etc. This survey helped in screening the frequency of WRMSD and other related aches or pain or discomfort in different body parts among the workers.

2.2 Review and Analysis of Working Posture and Biomechanics

Lynn McAtamney and E Nigel Corlett developed the RULA method for the upper body disorder analysis by considering biomechanical and postural load requirements. RULA is a quick assessment method that requires minimum tools like a clipboard, worksheet and pen. It evaluates the upper body, muscles efforts, exertion of force and repetitive movements responsible for muscle fatigue. Recently, the method was used in the precast industry (de Sousa Abreu and Neto 2017) and to evaluate the level of ergonomics risk of various tasks of construction work (Kulkarni and Devalkar 2018).

CATIA V5 is a CAD/CAM/CAE/PLE/3D surface modelling system software used for part designing, mechanical assemblies and generation of drawing. This software is equipped with human modelling and ergonomics analysis, like RULA analysis, push/pull, lifting and lowering analysis and biomechanical analysis. CATIA is widely used in a wide range of industries from conceptualization to manufacturing of complex designing development and simulation (Yogasara 2004).

The digital human model (DHM) of working postures of workers engaged in excavation work for the digging task was developed and analysis is carried out in CATIA V5 software using the RULA assessment tool and biomechanical analysis. Two postures are considered for this study and RULA score and biomechanical analysis of load on lumbar segment L4/L5 were carried out.

3 Results

The workers engaged in manual excavation work have mean (±SD) of age, height, weight, experience and BMI to be 40.69 (±9.39), 162.43 (±5.26), 61.11 (±5.72), 17.48 (±9.55) and 23.16 (±1.84), respectively. The duration of work depends on the work demand; the average working hours per day is 8–10 h with 1–1.5 h rest break.

During the study, all the workers reported some pain in the different body parts; among them, 47.62% of workers reported that they had pain or discomfort after working whose age is above 30 years and 21.43% of workers reported that they had pain in the morning whose age is between 45 and 50 years. The percentage of perceived pain or discomfort in the different body parts is shown in Fig. 1. From Fig. 1, it is revealed that the workers reported pain or discomfort in the lower back (83.33%), shoulder (83.33%), arms/hands (73.81%), wrist (40.48%), fingers/thumbs (30.95%), legs (26.19%), chest (21.43%), head (16.67%) and neck (7.14%).

No complaints about pain in the elbow, upper back, thigh/hip/buttock, knees and ankle/feet/toe. From the on-site observation and video-recorded observation, it was also found that 83.33% or more workers are working in awkward postures.

In this task, workers repetitively apply force to break the layer of the topsoil with the help of a pick-axe. All these working postures were observed and specifically selected awkward postures in the excavation work were video recorded. The most hazardous overworking postures and actions having the highest score in the RULA

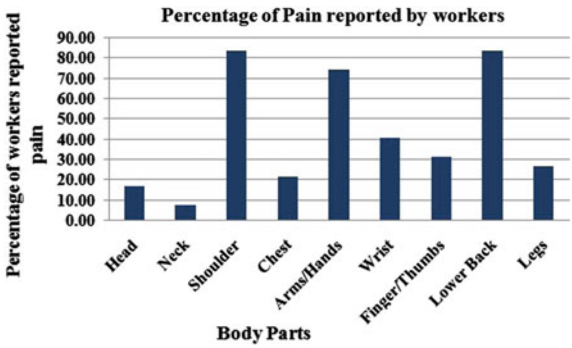
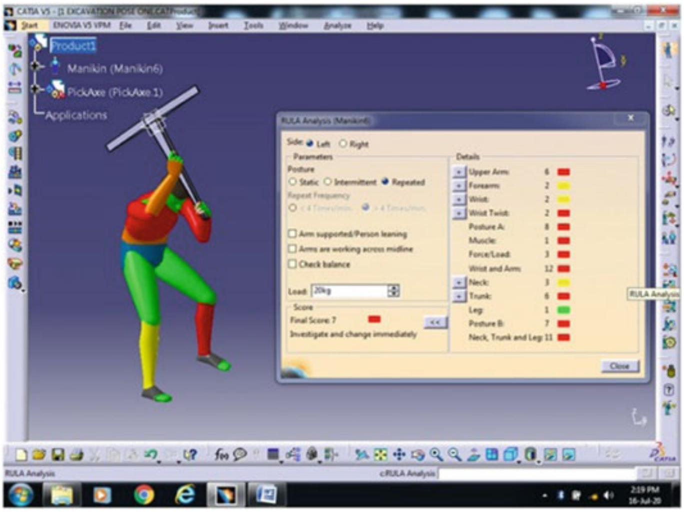


Fig. 1 Percentage of pain reported by workers

(a)

Fig. 2 **a** Real-time image of first body position. **b** RULA analysis of left side of the first position with worker holding pick-axe above the shoulder height. **c** RULA analysis of right side of the first position with worker holding pick-axe above the shoulder height



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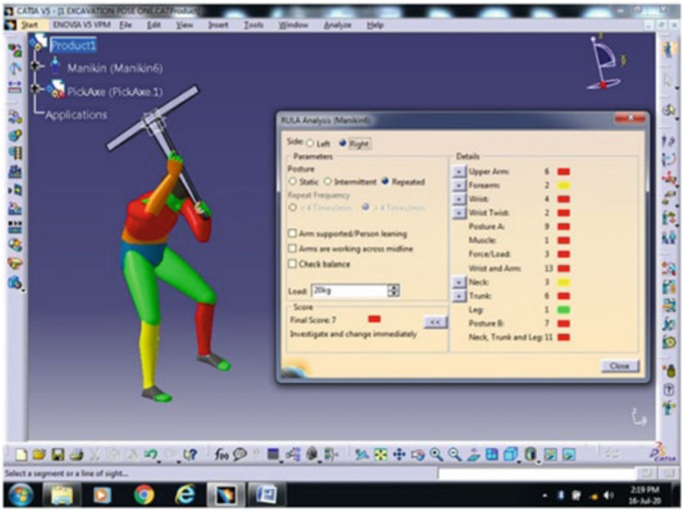

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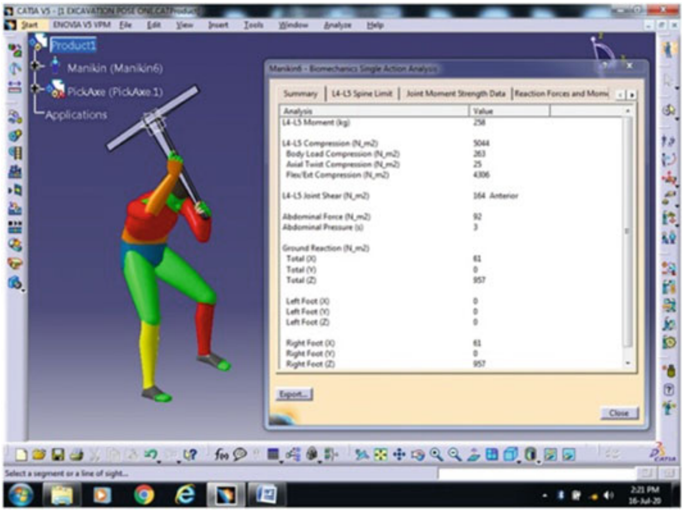

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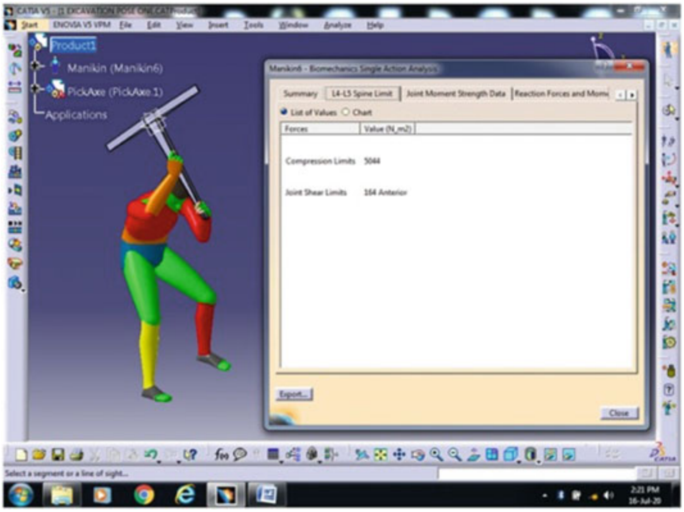

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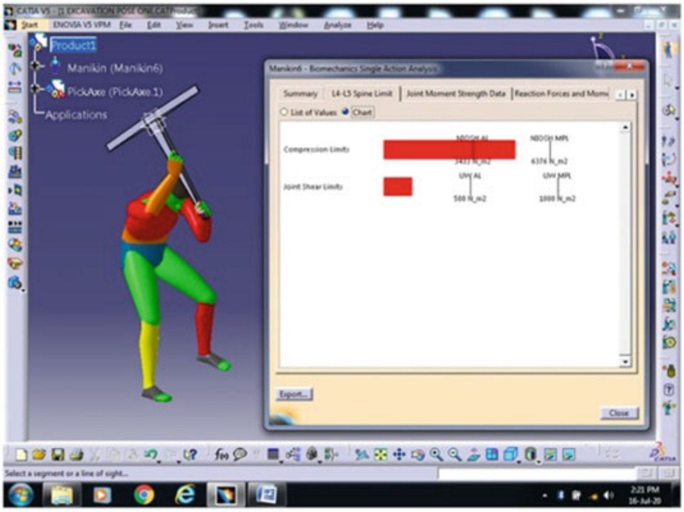
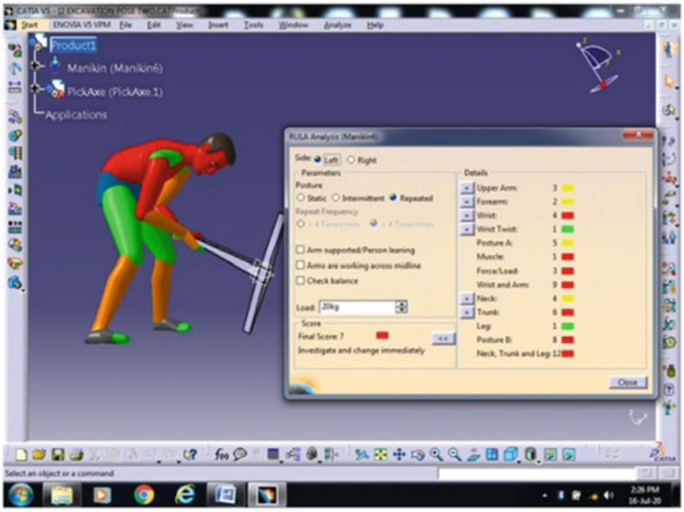


(f)

Fig. 2 (continued)

(a)

Fig. 3 **a** Real-time image of second body position. **b** RULA analysis of the left side of the second position with worker holding pick-axe below the shoulder height. **c** RULA analysis of the right side of the second position with worker holding pick-axe below the shoulder height. **d** Biomechanical analysis of the second position with worker holding pick-axe below the shoulder height. **e** Biomechanical analysis of the second position with worker holding pick-axe below the shoulder height. **f** Biomechanical analysis of the second position with worker holding pick-axe below the shoulder height



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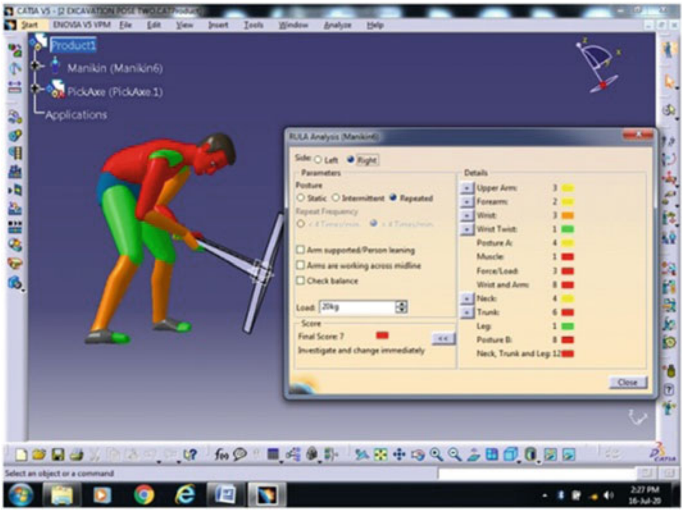

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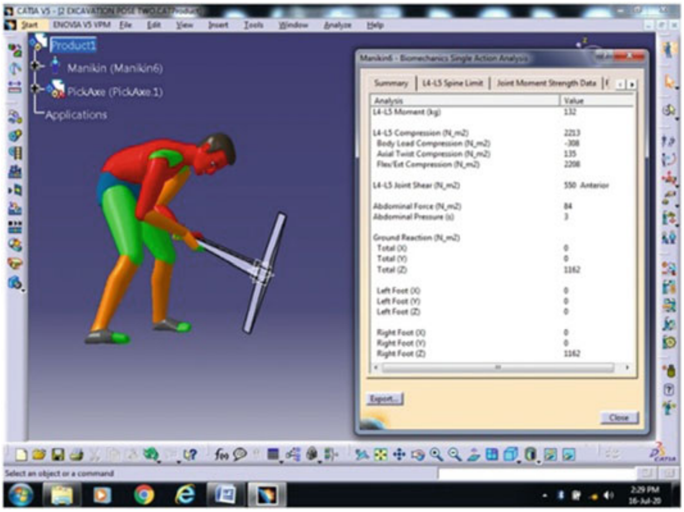

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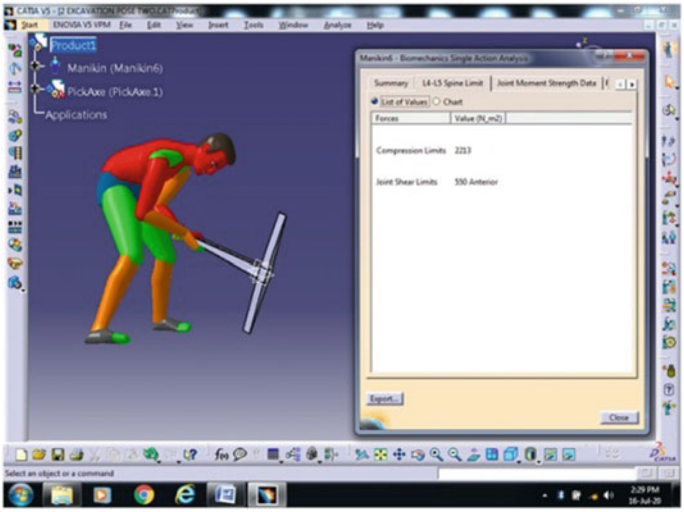

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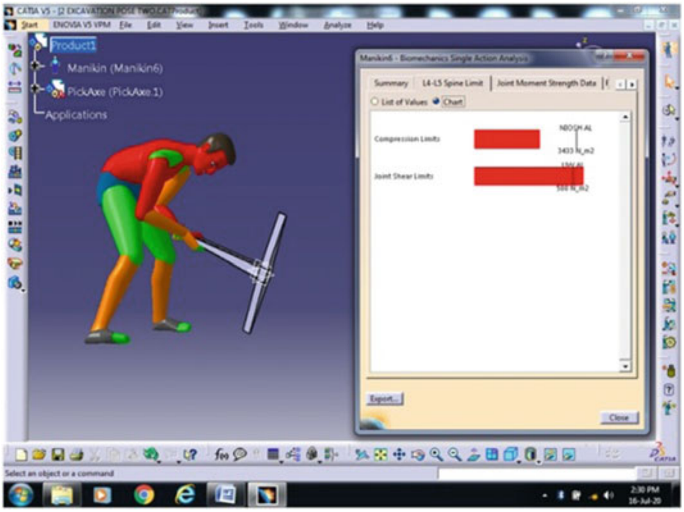

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Table 1 Workers' responses for pain in different body parts

Body parts	No. of workers	% 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

worksheet assessment were chosen for critical analysis. The appropriate computer manikins are designed in CATIA V5. Moreover, the RULA and biomechanical analysis were carried out (Table 1).

Risk factors like a repetition of work, static muscle load, force, working postures and no break time are considered while designing the manikin to produce the final result. The manikin degree of freedom for all body parts has been set as per the standard rule of anthropometry of population and assigned green, yellow, orange and red. The green colour indicates "acceptable posture", yellow indicates "need further investigation and change", orange indicates "need further investigation and change soon" as well as red indicates "need investigation and changes immediately".

3.1 Analysis of First Body Position

During this task, workers' perform excavation work extending their shoulder, trunk extension, sometimes twisting of the trunk, both arms above the shoulder, radial deviation of the wrist when both arms are above the shoulder, ulnar deviation of the wrist when both arms are below the shoulder, legs are in flexion position (bent) at knees in between 30° and 60° and legs abduction. Figure 2a–f shows real image and manikin developed in CATIA with its RULA and biomechanical results.

For first body position, the RULA scores of repetitions of work, static muscle load, force, working postures and no rest time were observed. The final RULA scores for the left and the right side were found to be more than 7 (red). From Table 2, it is revealed that this needs investigation and required immediate change. RULA score shows that arms, wrist, shoulder, neck, trunk and legs are highly affected.

From Table 3, the maximum lumbar torque is 258 Nm. The compression force on L4/L5 at this position is 5044 N, which is above the maximum limit of 3400 N recommended by NIOSH (Hlavkova et al. 2016; Afshari et al. 2018; Arjmand et al. 2015). The compression of L4/L5 is not appropriate and need to be reduced (Hlavkova

Table 2 RULA scores for first, second and new proposed conceptual body position

Working postures	Left			Right		
	Wrist/arms	Neck/trunk/legs	Total score	Wrist/arms	Neck/trunk/legs	Total score
First body position	12	11	>7	13	11	>7
Second body position	9	12	>7	8	12	>7
Proposed conceptual body position	5	4	5	5	4	5

Table 3 Biomechanical analysis on the spinal segment of L4/L5 of first, second and proposed conceptual body position

Parameters	Action limit		
	First body position	Second body position	Proposed conceptual body position
Torque (Nm)	258	132	38
Compression (N)	5044	2213	1131
Compression on body load (N)	263	−308	490
Axial twist compression (N)	25	135	0
Flexion/extension compression (N)	4306	2208	631
Joint shear load (N/m^2)	164 (Anterior)	550 (Anterior)	82 (Posterior)
Force on abdomen (N)	92	84	0
Pressure on abdomen (N/m^2)	3	3	0

et al. 2016; Afshari et al. 2018; Arjmand et al. 2015). The joint shear load of L4/L5 at this position is 164 N/m^2, which is below the maximum action limit of 500 N/m^2 and is appropriate (Hlavkova et al. 2016; Afshari et al. 2018; Arjmand et al. 2015). In this posture, 92 N force is applied on the abdomen with a pressure of 3 N/m^2. The detailed biomechanical result is presented in Table 3.

3.2 Analysis of Second Body Position

While doing excavation work, the worker's second position is shown in Fig. 3a–f. In this position, the tip of the pick-axe barge into the soil. Workers then need to apply force to remove the pick-axe; with that the layer of the soil is also removed. The workers' hazardous postures during this task are forward bending (flexion) of the trunk more than 90° at lumbar, arms below the shoulder height, twisting of trunk every so often, radial and ulnar deviation of the wrist, legs are in flexion position (bent) at knees between 30° and 60° and abduction position (Fig. 3a–f).

For this position, the final RULA (Table 2) score for the left and right sides was found to be more than 7 (red) which revealed that it needs investigation and required immediate change. The RULA score shows that upper arms, wrist, neck, lumbar and legs are deeply affected.

From Table 3, the maximum lumbar torque is 132 Nm when the worker is in this position. The compression at L4/L5 was found to be 2213 N which is under the maximum action limit of 3400 N. However, the joint shear load of L4/L5 at this position is 550, which is found to be above the maximum action limit of 500 N/m^2. It is not appropriate and not acceptable. In this position, 84 N force was applied on the abdomen with 3 N/m^2 pressure. The detailed biomechanical result is presented in Table 3.

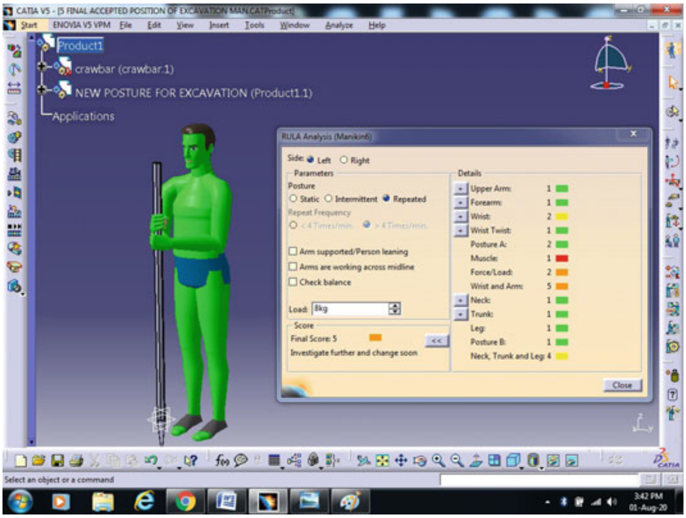
3.3 Design Concept for the Proposed Conceptual Working Posture

In conceptual design, the pick-axe is replaced by a crowbar for excavating the task. The weight of a crowbar ranges from 3 to 8 kg and is used for excavation. By using a crowbar, the workers can work in the posture shown in Fig. 4a–e. The RULA score for this working posture was derived and the score obtained for this posture for both right and left sides is found to be 5 (Table 2). At the same time, all the body parts are not exposed to any hazardous working posture. Also, the effort required for doing excavation work in this posture seems low.

From Table 3, the maximum lumbar torque at L4/L5 was found to be 38 Nm with L4/L5 compression of 1131 N which is less and is under the maximum action limit of 3400 N. Also, the joint shear at L4/L5 is 82 N/m^2, which is also below the maximum permissible action limit. The force and pressure on the abdomen were also found to be zero. The use of crowbars was found to be more feasible than the use of a pick-axe for the excavation work to work in the erect position.

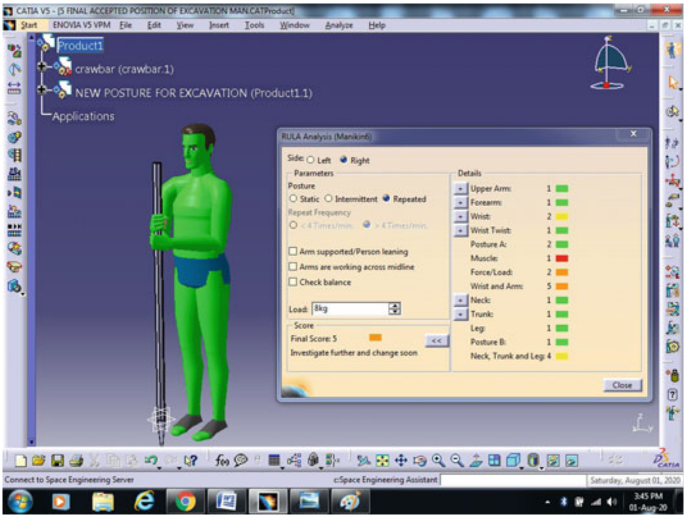
4 Discussion

CATIA V5 software was used for developing the real-life working posture of the excavation workers to find the effect of working in an awkward posture, forceful exertion, repetitive work, an overload of muscles on the different body parts of the workers with the effect of force/load on the spine at L4/L5 segment. The use of CATIA V5 software provides many features to create the working posture and carry out analysis of work. There are many other computational methods available



(a)

Fig. 4 **a** RULA score of the left side of the proposed working posture using a crowbar. **b** RULA score of the right side of the proposed working posture using a crowbar. **c** Biomechanical analysis of the proposed working posture using a crowbar. **d** Biomechanical analysis of the proposed working posture using a crowbar. **e** Biomechanical analysis of the proposed working posture using a crowbar



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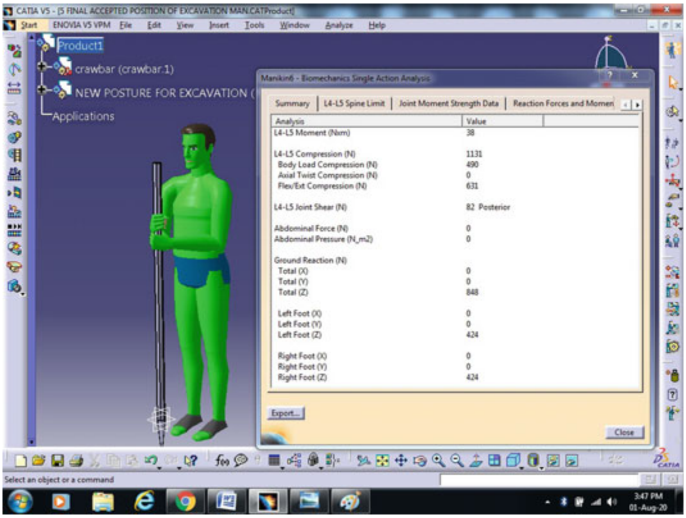

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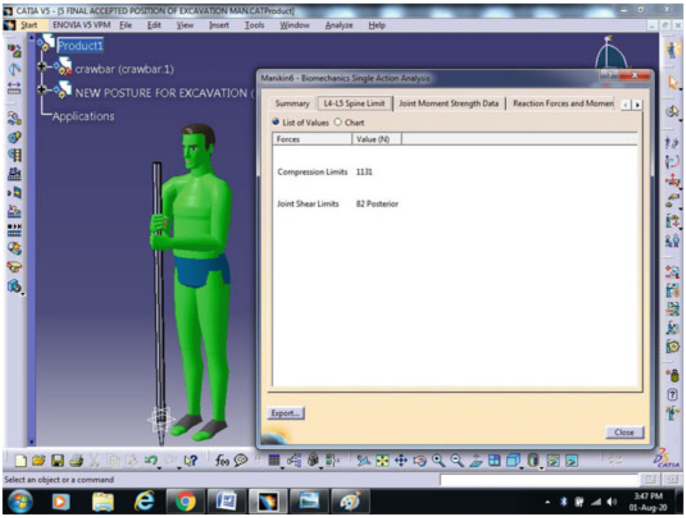

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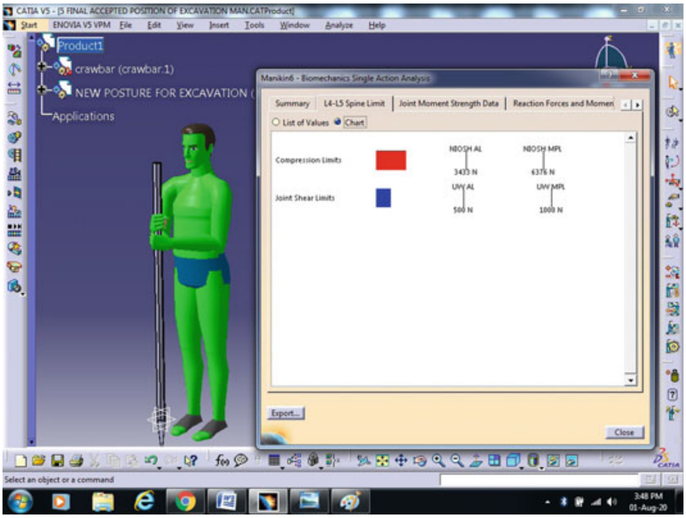

(e)

Fig. 4 (continued)

(Rahman 2011; Sanchez-Lite et al. 2013; Hashim et al. 2014; Pavlovic-Veselinovic et al. 2016) that can be used.

In this analysis, for the first position, the RULA score for both postures was found above the score of 7, which highlighted that it needs immediate corrections. The biomechanical analysis also shows that when the arms are above the shoulder level with heavyweight material and in the flexion position, the compression at L4/L5 is high.

For the second working position, the biomechanical analysis shows that compression at L4/L5 is low but joint shear load at L4/L5 is high and also bending forward at an angle of more than 90° is not acceptable, and as the flexion position increases the load on L4/L5 increases and will vary with body weight (Hlavkova et al. 2016). Many researchers have also started working in the construction area and highlighted the issues related to physical exposure among the construction workers (Antwi-Afari et al. 2017; Chen et al. 2017; Valero et al. 2016).

The recommended working posture with the proposed tool will help to minimize the force/load on different body parts and at L4/L5 of the spinal cord. Also, the workers are not required to bend forward and apply force only with arms only. RULA score shows that there is no adverse effect on body parts. From the biomechanical analysis, the compression and shear force on L4/L5 is under the maximum action limit suggested by NIOSH.

5 Conclusion

The RULA score shows that both the positions in which excavation work is carried out by the workers are at high risk. The biomechanical analysis revealed that the present working posture applies a high load on L4/L5 of the spinal cord. The suggested working posture with the working tool will minimize the effect of working in awkward posture and also minimizes the compressive as well as the shear load at L4/L5 lumbar segments of the spinal cord, which leads to the development of WRMSD in excavation workers.

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References

Afshari D, Latifi SM, Kord S, Nourollsahi-Darabad M (2018) Assessment of low back disorders risk based on allowable weight limits for manual lifting in Iran. Ind Health 56(4):327–335. https://doi.org/10.2486/indhealth.2017-0174

Antwi-Afari MF, Li H, Edwards DJ, Pärn EA, Seo J, Wong AYL (2017) Biomechanical analysis of risk factors for work-related musculoskeletal disorders during repetitive lifting task in construction workers. Autom Constr 83:41–47. https://doi.org/10.1016/j.autcon.2017.07.007

Arjmand N, Amini M, Shirazi-Adl A, Plamondon A, Parnianpour M (2015) Revised NIOSH lifting equation may generate spine loads exceeding recommended limits. Int J Ind Ergon 47:1–8. https://doi.org/10.1016/j.ergon.2014.09.010

Chen J, Qiu J, Ahn C (2017) Construction worker's awkward posture recognition through supervised motion tensor decomposition. Autom Constr 77:67–81. https://doi.org/10.1016/j.autcon.2017.01.020

Hashim N, Kamat SR, Halim I, Othman MS (2014) A study on push-pull analysis associated with awkward posture among workers in aerospace industry. IJRET Int J Res Eng Technol. ISSN: 2319-1163 pISSN: 2321–7308. https://www.researchgate.net/profile/Seri_Kamat/publication/260294407

Hlavkova J, Lebeda T, Tichy T, Gadourek P, Urban P, Nakladalova M, Lastovkova A, Fenclova Z, Ridzon P, Ehler E, Richter M, Pesakova L, Pelclova D (2016) Evaluation of lumbar spine load by computational method in order to acknowledge low-back disorders as occupational diseases. Central Eur J Public Health 24(1):58–67. https://doi.org/10.21101/cejph.a4332

Kulkarni VS, Devalkar RV (2018) Postural analysis of building construction workers using ergonomics. Int J Constr Manag 1–8.https://doi.org/10.1080/15623599.2018.1452096

Pavlovic-Veselinovic S, Hedge A, Veselinovic M (2016) An ergonomic expert system for risk assessment of work-related musculo-skeletal disorders. Int J Ind Ergon 53:130–139. https://doi.org/10.1016/j.ergon.2015.11.008

Abd Rahman MN, Rani MRA, Rohani JM (2011) WERA—an observational tool develop to investigate the physical risk factor associated with WMSDs. J Hum Ergol 40:19–36. https://www.jstage.jst.go.jp/article/jhe/40/1_2/40_19/pdf

Sanchez-Lite A, Garcia M, Domingo R, Angel Sebastian M (2013) Novel ergonomic postural assessment method (NERPA) using product-process computer aided engineering for ergonomic workplace design. PLoS One 8(8):e72703:1–12. https://doi.org/10.1371/journal.pone.0072703 de Sousa Abreu E, Neto HCA (2017) Ergonomic work analysis: a case in precast industry from the use of OWAS and RULA methods. Int J Mater Mech Manuf 5(1):68–71. https://doi.org/10.18178/ijmmm.2017.5.1.292

Valero E, Sivanathan A, Bosché F, Abdel-Wahab M (2016) Musculoskeletal disorders in construction: a review and a novel system for activity tracking with body area network. App Ergon 54:120–130. https://doi.org/10.1016/j.apergo.2015.11.020

Yogasara T (2004) The use of computer aided design (CATIA V5 R8) for ergonomics analysis. Seminar Ergonomi, Yogyakarta, pp 356–364. http://ti.unpar.ac.id/wp-content/uploads/sites/10/2016/09/Thedy04_Seminar-Nasional-Ergonomi-2_2004.pdf