An Experimental Study of Force Involved in Manual Rebar Bending Process

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Abstract. The work presents an experimental method of understanding the force applied during a manual rebar bending process. The study tracks the force with the variation of the angle of bend and the elapsed time from the start to the end of a complete manual rebar bending process. A sample of expert rebar bending labourers are used for conducting the experiment and the data processed to set a performance standard. If a simulator based rebar bending training can be provided for a novice, this standard can be used as a matrix to define how close a novice rebar bender is closing to the expertise.

1. Introduction
The construction industry is the second largest employer in India providing employment to more than 35 million people, that is about 16 percentage of India’s working population[1]. Though the industry generates employment opportunities on a large scale, over 80 percentage of the workers are unskilled[2]. To compound to the already existing problem of lack of skilled manpower, the planning commission estimated an infrastructure investment of Rs 41 lakh crores or nearly one trillion USD over the duration of the Twelth Five Year Plan (2012-2017) in order to sustain a real GDP growth rate of 9 per cent[3]. These statistics emphasis the ever increasing need for skilled workers to meet the targets of the burgeoning Indian construction industry.

Rebar bending, one of the main trades in the construction industry, involves bending steel rods to act as a tension device to strengthen and hold the concrete that is used to build concrete structures[4]. Depending on the architecture of the concrete structures, a rebar bender might have to bend the steel rods into a standard shape like square, rectangle, triangle, circle, crank etc. The government of India has defined a national occupational standard for the process of rebar bending and the skills involved in the rebar bending process[6, 7]. According to the standard, ”Bar bender and steel fixer” is a person skilled in cutting and bending straight rebars into these standard shapes[5]. According to US term Iron worker is trades man or women who working in iron working industry. Their jobs are distributing as follows, unloading, placing and tying the rebar as well as install post tensioning systems which are same as job of rebar bender and steel fixer[6]. To master and perfect this skill, systematic and structured vocational skill learning opportunities in India are few and far between. Hence, only after several years of on-the-job experience, bar benders develop the required skills and attain proficiency in the process of rebar bending[7]. Usage of computerized automated bar bending machines could reduce the time required to make a bend and increase quality and quantity of the bend. But the
huge initial investment needed as well as the need for technical skilled personnel to operate the machines makes it a prohibitive option. Also, it has been observed that even though automated bar bending gives more productivity, it also introduces the problem of inaccuracies in quantity estimates[9]. Hence, manual skilling in rebar bending might be the most economically viable option for India today.

In India, government institutions and private institutions give training to their work force to progressively improve their knowledge and competencies for their assigned job roles[10, 11, 12]. The number of people educating from this ITIs and ITCs are very less[13]. The training centres usually take 2 to 6 months to train a novice to become an expert in the bar bending process. However, during the training cycle, there is a lot of material wastage incurred. To mitigate this problem, bar bending training using haptics simulators provides an option to save money, material and time, thereby benefiting both the training institutes and the trainers[14].

Before one embarks on developing a haptic simulator for manual skill training, it is essential to develop an understanding of the governing physics and the underlying mathematics needed to quantify the system behavior. Modelling is a good approach to help explore solutions for a complicated process such as bar bending skill training. To start modelling, first we need to understand what are the skill parameters involved in the manual rebar bending process[15, 16]. When we compared the automated bar bending process with the manual rebar bending process, we observed that the user gave a bend angle and a bending radius to the machine and it automatically processed this information to bend the bar. In manual rebar bending process, the rebar bender exerted force on the bar as well as applied some motor skills to bend the rebar to the desired angle. Based on these observations, we selected the force of bend, angle of bend and time of bend as the initial skill parameters to study to develop an understanding of the bar bending process.

The rest of the paper presents the steps involved in the manual rebar bending process and presents an evaluation of the effect of force of bend, angle of bend and time of bend during each bending process. We also present the design of an experimental set up that captures and records the above mentioned skill parameters in order to understand the variations between an expert bend and novice bend.

2. Related Work

Initially very little interests were received to reinforcement manufacturing industry from the research world. V. Balasubramanian et.al had worked on the manual rebar bending process and they done there study for realizing the back bone problems while you were doing the manual rebar bending by adjusting the table height and grip arm distance[20]. In 2008 the same team done an EMG-based ergonomic evaluation of manual rebar bending. Based on this study they can suggest optimal conditions for increase worker safety and enhance their output[21]. Waleed Umer et.al identified the risks factors for the Development of Lower-Back Disorders during Manual Rebar Tying the process which comes after the rebar bending process[22]. In the above studies authors were nding solutions or protection to the consecutive labours during their works, since it contains that much risks and dangerous same as very much skilling involved.

Dunston et. al discuss the spring back phenomenon and enumerate the force patterns and spring back effects on the bar while bending the rebar in an automated bending machine[18]. Prior research done by the Dunston et. al[17] in 1993 discusses the cold forming properties and mechanical behaviour of the rebar. They also present an implementation of a computer controlled rebar bending process in this work.

Another detailed study done by Chang Hwan Choi et. al showed the spring back phenomenon for different bar diameters and different bending angles[19]. The positive and negative correlation of the spring back with different parameters such as diameter of the bar, yield strength, bending radius and bend angle has also been discussed. This study was also carried out with an
automated bar bending machine. To our knowledge, there has been no prior work done to study the skill parameters for manual rebar bending. Hence there is a need to undertake detailed research and analysis of the manual rebar bending process to study skill parameters such as force, angle and time of bend. These parameters can be used to enhance the effectiveness of any bar bending training procedure.

### 3. Manual Rebar Bending Process

A manual rebar bending setup is shown in Figure 1. A three pin metal plate is attached on the top of a table and the table height is varied between 800 cm and 1200 cm. Figure 2 shows the top view of the three pin table with the rebar and a lever that assists with the rebar bending.

![Figure 1. Rebar bender bending the 8mm diameter rebar](image)

Balasubramanian et. al[21] present the characteristics of a typical worktable and different bar details. The bar and lever are positioned in between the three pins on the work table. The lever is placed on top of the rebar. The bar bender holds his right hand on the lever at position B, which is 'c' cms apart from the bar and places his left hand on the bar at position A, which is 'b' cms apart from the pin table. The lever will be positioned 'a' cms away from the first pin of the three pin table. The bar bender, then applies the required force in order to bend the rebar. Normally, different bar diameters can be bent using the same three pin table. This is the general process for bending 8 mm and 10 mm diameter rebars, which are the most commonly used rebar diameters.

### 3.1. Governing Parameters

The critical parameters involved in a rebar bending process can be classified as fixed and variable parameters. Fixed parameters include diameter of the bar, material of the bar and pressure points which are constant values, that is, they will not vary while bending the bar. The three variable parameters, bending force, angle of bend and time of bend depend upon the expertise of worker involved. So these three parameters are the point of interest in our study.

### 3.2. Resultant Force Calculation

The force required to bend the bar is a function of diameter of the bar and yield stress of the material of the bar. Figure 2 shows the direction of the force components on both the lever and the bar. The bar bender will pull the lever using his right hand towards himself. So the resultant force \( F_1 \) will be acting with an angle \( \theta \) as shown in the figure. The force component on both the axis can be represented as sine and cosine values of the applied force. In the case of bar itself, the bar bender applies a force by pushing his left hand, which will result in a force
Figure 2. Top view of the manual rebar bending process

F2 at an angle of . A bar bender applying both forces on the lever and the bar using his right and left hands will provide a resultant force T that can be expressed as equation (1).

\[ T = cF_1 \sin \theta + aF_1 \cos \theta + bF_2 \cos \phi \]  

Typically, a bar bender uses his left hand to just hold the bar. He is not applying any force to the bar. Hence, F2 component will be zero. Considering that the degree, F1 cos will be equal to zero. So final equation will get simplified to equation (2).

\[ T = cF_1 \sin \theta \]  

According to the literature, rebar spring back is a function of several parameters and it is difficult to predict it in real-time [16, 17]. In our study, we have not considered the spring back factor.

4. Experimental Study

4.1. Experimental Setup

An experimental setup was designed to measure the variation of the variable parameters during the manual rebar bending process. Figure 3 shows the rebar bender bending the rebar using the experimental setup. There was no difference observed between the process of bending the rebar on the experimental setup vis-à-vis the process on the three pin table.

Figure 4 shows an experimental setup which included a CZL 601 single point load cell that was attached to the three pin plate for measuring the applied force. A Bourns 10K hollow shaft potentiometer was used as an angle measurement sensor which was aligned with the bending axis of the three pin plate. A shaft coming from the potentiometer was connected to the rebar. In the manual bending operation, as explained earlier, the bar bender applies force on the lever using his right hand. So the corresponding force values from the load cell and angle values from the potentiometer can be read and recorded.

During experimentation we found that when the rebar bender applied a force to bend the rebar, the load cell would start to sense the force. But the potentiometer will not start reading because there was no movement happening on the potentiometer shaft. This phenomenon could
be explained by the plastic-elastic theory. Only after the elastic region of the mild steel bar is crossed will the potentiometer start reading.

The load cell and potentiometer were connected to a PIC32 micro controller which was working at 80 MHz frequency to collect data from the manual rebar bending process. Both the sensors were connected to the ADC of the micro controller to get the corresponding digital values. The equivalent force in kilogram and angle in degree were sent to the computer through the micro controllers serial port for further processing. Figure 5 shows the architecture of the hardware.
4.2. Procedure
Calibration of the load cell was done using a sub circular type round spring balance scale by applying known forces and calibrating the sensor in the designed experimental set up. During the calibration, the spring balance was held 40cms away from the lever. When the user pulled the spring balance, the rebar would bend. We recorded the reading of the spring balance which varied between 12kg to 14kg. Then we calculated the torque needed to bend a 8 mm diameter rebar which came out to be approximately 50Nm.

We selected experts and novice based on the number of years of experience in rebar bending. A worker with over ten years experience was considered as an expert while a novice did not have any experience in the bar bending process. We selected two experts and two novices for the initial experiments. We had them bend 20 square shaped rebars where each shape had 5 bends. So we recorded a total of 100 bends, 50 bends from experts and 50 from the novice. For the bending experiment, we only considered the square shape rebar bending. Each bend should be exactly 90 degrees. Based on the dimensions of the square shape, the worker had to mark the specimen bar at the points where he needed to bend. Both the experts and the novices bent each rebar five times. The workers were instructed to hold their right hand 40 cm away from the three pin table. This was a constraint we placed on every trial.

5. Results and Discussions
The observed data has to be analyzed to understand the variations of force of bend, angle of bend and time of bend for each bend, with respect to expert and novice. Based on these differences in data we can classify nature of the bend of experts and novices.

Figure 6 shows the force versus time and force versus angle plot of expert In the figure the maximum force exerted by the user concentrated on the calibrated force, so the plastic region is set as in this region. we realized that the maximum angle of bend is happens in the peak of each bend. But you can’t see same force pattern while you close to 90 degree of bend. Then this force becomes narrow as shown in the figure. Also analyzing the data of novice we realized that, they applying force more than that and force patterns are very inconsistent which is explained in the below force of bend section. From comparing the force of bend, angle of bend and time of bend of experts to novice, noticeable differences obtained. So based on the difference in above skilled parameters, below listed the analysis.

5.1. Force of Bend
During the calibration test measurements of the bending force for bending the 8mm diameter bar was noted. Experiments were carried out using spring balance with a distance of 40cm from the 3 pin table with the lever and found out that approximately 12-14kg force has to be applied to bend 8mm diameter bar. The experts bend the 8mm diameter bar by applying approximately 12 -15kg maximum force at 40cm on lever. While the novices applies maximum force which more...
than 15kg to bend the bar. The below figure 7 will give the difference of applied force comparing experts and novice. Also novices force is not stabilized force compared with expert.

![Figure 7](image)

**Figure 7.** Experts and novice: force vs time graph

The blue plot (series 1) gives the expert’s bend and red plot (series 2) gives the novices bend. Figure shows that force applied by the expert was keeping in the calibrated force range and which will be approximately 15kg. Out of 25 bends of expert1 20 bends was less than 16kg. In same way 22 bends of expert2 was also approximated up to 16kg. While in same case novices were applying more than 16kg force, and sometimes the force applied up to 20kg. Out of 25 bends 20 bends novice1 applied was more than 16kg force in which 6 bends were up to 20kg. Novice2 applied 19 bends out of 25 bends was more than 16kg and 17 bends applied more than 20kg force. Figure 8 shows the force patterns of the novice1 and novice2 in which each section illustrate the 3 different types of bending force.

![Figure 8](image)

**Figure 8.** Novice1 and novice2: force vs time graph

5.2. **Angle of Bend**

For accuracy of each 90 degree bend of the rebar has given tolerance up to +/- 5 degree. So according to this rule angle has to keep in between 85 degree to 95 degree. Expert users bends with respect to the angle which keep 90 degree as intended. According to above rule expert keep 100 percentage of accuracy, in their bends, but novice has 40 percentage in the same. Figure shows the sample plot of difference between the experts and novices bend. Figure 9 shows the experts force versus angle of bend graph which illustrate the accuracy of the angle of experts bend and Figure 10 shows the sample graphs for novices bend.

5.3. **Time of Bend**

Average time taken by the expert1 to bend 90 degree bend is 17.12 seconds and for expert2 is taken only 11.2 seconds. But in case of novice1 time taken were 19.3 seconds and novice2
It was observed that expert was bending better in each trial while comparing to previous trial in considering the force applied, angle accuracy, and time taken. From the results obtained, we could infer that 84 percentage of experts are exerting a stabilized force in the range of 12-15kg while bending the rebar and at the same time, only 22 percentage of the novices are exerting the force in the above mentioned range. Thus bending force can be used as a parameter for distinguishing an expert and novice bar bender. So during the bending after the analyzing of each trail data, the trainer can teach the problems of the last bend in terms of force applied, angle of bend and time taken. So if the force applied is correct which is equal to calibrated force then the rebar bender will get a momentum angle of accuracy will be good and time taken will be minimum.

Manual assessment of the bend shapes from the experimental trials is assessed of experts and novice. Apart from experimental trial post survey has been carried with the expert to validate the experimental set qualitatively by following feedback.

1. force feedback from the original process
2. steps of original process
3. verify their output by themselves

Both experts given positive feedback on comparing experimental set up to actual process force. Expert User’s checked their trial pieces to compare with the field trials and given positive feedback on the same along with the process.

6. Conclusions and Future Work
This paper presents data on the force applied, angle of bend and time taken while bending a rebar manually. It captures the differences between experts and novice. Using this captured data,
information we can build a simulator to train a novice to become proficient in rebar bending. As future work, we need to consider parameters like lever positioning, body shifting etc and add this to the force model. These models will provide an accurate mathematical model to build a simulator that can train a novice to become an expert bar bender.

References
[1] Indian Construction Industry Overview, http://www.indianconstructionindustry.com/overview.html , [online]
[2] Skill Development In Construction Sector, http://www.skillconindia.in/skillcon2013_presentations /DAT_2_13_08_2013/SCSBIAG/DrMangeshKorgaonker.pdf, [online]
[3] Working Sub-Group on Infrastructure, http://planningcommission.gov.in/aboutus/committee /wg_sub_infrastructure.pdf, [online]
[4] Rebar, https://en.wikipedia.org/wiki/Rebar, [online]
[5] Model Curriculum, http://www.nsdcindia.org/sites/default/files/files/MC_BarBenderSteelFixer.pdf, [online]
[6] Ironworker, https://en.wikipedia.org/wiki/Ironworker
[7] QUALIFICATIONS PACK- OCCATIONAL STANDARDS FOR CONSTRUCTION INDUSTRY, http://www.nsdcindia.org/sites/default/files/files/Bar-Bender-Steel-Fixer-Level3.pdf, [online]
[8] Model Curriculum Bar Bender Steel Fixer, http://www.nsdcindia.org/sites/default/files/files/MC_BarBenderSteelFixer.pdf, [online]
[9] Lim, C., Hong, W. K., Lee, D., Kim, S. (2016). Automatic Rebar Estimation Algorithms for Integrated Project Delivery. Journal of Asian Architecture and Building Engineering, 15(3), 411-418.
[10] Akshay, N., Deepu, S., Bhavani, R. R. (2012, January). Augmented vocational tools using real time audiovisual feedback for psychomotor skill training. In Technology Enhanced Education (ICTEE), 2012 IEEE International Conference on (pp. 1-4). IEEE.
[11] Certificate in Bar Bender Skills, http://www.manipalcityandguilds.com/Construction/BarBendingSkills.aspx, [online]
[12] Construction Skill Training Institute, http://www.lntecc.com/HOMEPAGE/CSTI/index.htm, [online]
[13] Vocational Education in India, http://www.nistads.res.in/indiastat2008/t1humanresources/t1hr2.htm
[14] Akshay, N., Deepu, S., Rahul, G., Ranjith, R., Jose, J., Unnikrishnan, R., Bhavani, R. R. (2013, November). Design and evaluation of a Haptic simulator for vocational skill Training and Assessment. In Industrial Electronics Society, IECON 2013-39th Annual Conference of the IEEE (pp. 6108-6113). IEEE.
[15] Chou, M., Xia, X., Kayser, C. (2007). Modelling and model validation of heavy-haul trains equipped with electronically controlled pneumatic brake systems. Control Engineering Practice, 15(4), 501-509.
[16] Bernold, L. E. (1991, June). Process driven automated rebar bending. In Proc. 8th Int. Symp. on Automation and Robotics in Construction (pp. 639-646).
[17] Dunston, P. S., Bernold, L. E. (1993). Intelligent control for robotic rebar bending. In Proceedings of the Tenth International Symposium on Automation and Robotics in Construction, Houston, TX, May (pp. 24-26).
[18] Dunston, P. S., Bernold, L. E. (2000). Adaptive control for safe and quality rebar fabrication. Journal of construction engineering and management, 126(2), 122-129.
[19] Choi, C. H., Kulinsky, L., Jun, J. S., Kim, J. H. (2014). A Numerical Study of the Spring-Back Phenomenon in Bending with a Rebar Bending Machine. Advances in Mechanical Engineering.
[20] Balasubramanian, V., Prasad, G. S. (2007). Manual bar bendingAn occupational hazard for construction workers in developing nations. Journal of construction Engineering and Management, 133(10), 791-797.
[21] Balasubramanian, V., Swami Prasad, G. (2007). An EMG-based ergonomic evaluation of manual bar bending. International Journal of Industrial and Systems Engineering, 2(3), 299-310.
[22] Umer, W., Li, H., Szeto, G. P. Y., Wong, A. Y. L. (2016). Identification of biomechanical risk factors for the development of lower-back disorders during manual rebar tying. Journal of Construction Engineering and Management, 143(1), 04016080.