Assessment of Different Factors Affecting Productivity and Cycle Time of Back Hoe Excavators

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Abstract- *In every construction project some type of excavation must be performed. The earthmoving equipment market in India is estimated at about US$ 1.4 billion. Excavators are extensively used in many roles such as digging of trenches and foundations, demolition, general grading/landscaping, heavy lifting, river dredging, mining and brush cutting with hydraulic attachments. The activities involved in construction projects where the magnitude of the work is on a large scale, speedy work and timely completion of work with quality control are very vital. In order to achieve this, mechanization of work has to be done where construction machinery and equipment play a pivotal role. Proper use of appropriate equipment contributes to economy, quality, safety, speed and timely completion of the project. Hence this study focuses on identifying the causes of productivity loss, evaluating their effects, evaluating their performance and to understand how the machine is used and how different conditions at site relate to its productivity and reliability. Time motion studies were conducted for measurement of a cycle time is to determine equipment performance and operator efficiency. This real time monitoring of the heavy equipment can help practitioners improve machine intensive and cyclic earthmoving operations. At the end of the session, it was clear that minutes saved per cycle meant nothing if the machine did not have properly trained operator.*

Keywords - *Bucket Size, Cycle Time, Excavator, Productivity, Production Performance Ratio*

I. INTRODUCTION

The Indian Construction Equipment sector has been growing due to the large investments made by the Government and the private sector infrastructure developments. The Indian market is catered by about 200 domestic manufacturers (small, medium & large). India is one among the top 10 markets for construction equipment and is one of the key international markets. The growth in this industry is expected to be primarily due to investments in infrastructure, investments by the Government in the form of external borrowings and internal accruals by Public-Private-Partnerships (PPP) model (A report by KPMG for IBEF).

Excavators are extensively used in many roles such as digging of trenches and foundations, demolition, general grading/landscaping, heavy lifting (e.g. lifting and placing of large concrete pipes), river dredging, mining and brush cutting with hydraulic attachments. Hydraulic excavator is a self-propelled crawler or wheel mounted machine, with an upper structure, capable of minimum 360° rotation, which excavates, elevates, swings and discharges material by the action of bucket fitted to the bottom and arm or telescopic boom, without moving the chassis or under-carriage during any part of working cycle of the machine. Excavators come in a range of capacities and are usually classified on the basis of tonnage. The lower end excavators, referred to as mini excavators, find greater usage in urban infrastructure development and road development. The heavier duty excavators are used in mining and heavy construction. In India, the level of technology of the equipment manufactured is at par with international standards with some exceptions being the limited usage of electronic controls and hydraulic systems and engines adhering to the latest emission norms.

The activities involved in construction projects where the magnitude of the work is on a large scale, speedy work and timely completion of work with quality control are very vital. In order to achieve this, mechanization of work has to be done where construction machinery and equipment play a pivotal role. The need for mechanization arises due to the reasons such as, magnitude & shortage of skilled and efficient manpower, optimum use of material, manpower and finance, importance of keeping the time schedules, high quality standards, complexity of projects, projects involving large quantities of material handling.

Proper use of appropriate equipment contributes to economy, quality, safety, speed and timely completion of the project. Construction equipment is an important part of any construction process. It is not always desirable or possible for the contractor to own each and every type of construction equipment required for the project. Considering the various aspects of the utility of particular equipment, the contractor has to economically justify whether to purchase the equipment or to hire it. The amount invested in the purchase of equipment should be recovered during the useful period of such equipment.

II. OBJECTIVES

The broad objective of the work is to identify the causes of productivity loss, evaluating their effects, evaluating their performance and to understand how the machine is used and how different conditions at site relate to its productivity and reliability. The production performance ratio compares the actual productivity against the estimated productivity to demonstrate the amount of loss of productivity and, thus, judge the level of productivity.

Cycle times can be one of the more puzzling aspects of open -pit excavation. Depending on one's perspective' the term has several connotations. A hoe operator might view a cycle time as the point from which the bucket dumps to the point where it dumps again, while a truck driver might view it as the time it takes to complete a circuit from the face to the dump point and back.

Measurement of a cycle time is to determine equipment performance and operator efficiency. Those statistics also serve as a measure of efficiency of the entire operation. Unusually high reading in certain segments can highlight problems. By measuring cycle times, benchmarks can be established, allowing the quick check that all is well.

Hydraulic hoe productivity as it relates to cycle times. At the end of the session, it was clear that minutes saved per cycle meant nothing if the machine did not have properly trained operator.

Another objective is to find out the Relative Importance Index (RII) of different factors by on-site observations and by taking opinions of related Engineers and Managers to determine relative importance of factors that influence the performance of excavating equipment. The RII was used to rank those different factors which made it possible to cross compare the relative importance of those factors.

III. METHODOLOGY

The details of the methodology adopted for the work is as narrated below.

A. Phase I

Backhoe is the most commonly used equipment for excavating operations in India. Hence, first of all the study of available literature on the backhoe excavator is done for understanding basic parts and operations of the machine. This part also includes study of estimated hourly production chart of excavator, study of fill factors for Hydraulic Hoe Buckets, swell factors and angle of swing.

B. Phase II

Most of the construction estimating procedures used today are conducted in a deterministic manner, this assumes that a specific value can be obtained for each cycle element time of the construction operation and the summation of these cycle element times, therefore, establishes the total time for the entire operation. It includes identifying different factors that affect cycle time and productivity of excavator.

C. Phase III

Next part is selection of a site for collecting the data by real time monitoring of an excavator by time motion study of hydraulic hoe to find out how the productivity of excavator is affected by various factors such as varying soil conditions, skill of operator, angle of swing, position of dumper, bucket capacity and number of dumpers, etc.

D. Phase IV

Calculation and analysis of actual and of theoretical production of hydraulic hoe by considering different factors such as bucket capacity, cycle time and fill factor and generating the comparative data, graphs finding Production Performance Ratio which will help the practitioners improve machine intensive and cyclic earthmoving operations and it can also provide reliable data for future planning.

IV. THEORETICAL CONTENTS

A. Hydraulic Hoe:

The hydraulic excavator is most commonly used for digging rocks and soil, but with its many attachments it can also be used for cutting steel, breaking concrete, drilling holes in the earth, laying gravel onto the road prior to paving, crushing rocks, steel, and concrete, and even mowing landscapes. Hydraulic excavators are designed to excavate below the ground surface on which the machine rests. These machines have good mobility and are excellent for general-purpose work, such as excavating trenches and pits. Because of the hydraulic action of their stick and bucket cylinders, they exert positive forces crowding the bucket into the material to be excavated.

B. Bucket Fill Factors for Hoe Buckets:

Rated heaped capacities represent a net section bucket volume; therefore, they must be corrected to average bucket load based on the material being handled. Fill factors are percentage which when multiplied by heaped capacity, adjust the volume by accounting for how the specific will load into bucket. For evaluating heaped capacity, hoe buckets are rated with an assumed material repose angle of 1:1. Therefore, actual bucket capacity depends on the type of material being excavated as all materials have their own natural repose angle. Table provides bucket fill factors for hoe buckets based on material type.

TABLE I

Bucket Fill Factors

Material Fill Factor	(Percent)
Moist loam or sandy clay	100 to 110
Sand and gravel	95 to 110
Rock (poorly blasted)	40 to 50
Rock (well blasted)	60 to 75
Hard, tough clay	80 to 90

C. Representative cycle time for backhoes:

TABLE II

Representative Cycle Time

Bucket size (CY)	Load bucket (Sec)	Swing loaded (Sec)	Dump bucket (Sec)	Swing empty (Sec)	Total cycle time (Sec)
<1	5	4	2	3	14
1-1.5	6	4	2	3	15
2-2.5	6	4	3	4	17
3	7	5	4	4	20
3.5	7	6	4	5	22
4	7	6	4	5	22
5	7	7	4	6	24

V. DATA COLLECTED AND OBSERVATION

TABLE III

Factors Considered

Factors	Site 1	Site 2	Site 3	Site 4	Site 5
Type of Soil	Dry Earth and Moorum	Dry Earth and Moorum	Earth and Gravel	Earth and Gravel	Dry Clay
Bucket Capacity	1.2	1	0.9	0.9	0.9
Cycle Time (Theoretical)	15	15	15	15	15
Cycle Time (Recorded)	19	21	23	19	23
Production (by Theoretical Time)	143.64	140.7	124.32	126.63	129.3
Production (by Recorded Time)	113.4	100.5	81.08	99.97	84.36
Operator Skill	Good	Poor	Poor	Very Poor	Average
Angle of Swing	90	150	170	110	130
Height of Cut	1 m.	2 m.	2 m.	1 m.	1 m.
Fill Factor	1.05	1.05	1.05	1.05	1.05
Swell Factor	20	20	35	20	35
Efficiency	0.57	0.67	0.74	0.67	0.77
Condition of Equipment	Average	Average	Good	Average	Good

Factors	Site 6	Site 7	Site 8	Site 9
Type of Soil	Dry Earth and Boulders	Moorum and Boulders	Dry Earth and Moorum	Earth Dry
Bucket Capacity	0.9	0.92	0.92	0.9
Cycle Time (Theoretical)	15	15	15	15
Cycle Time (Recorded)	21	25	19	16
Production (by Theoretical Time)	139.86	129.44	129.44	152.40
Production (by Recorded Time)	99.9	77.66	102.2	142.88
Operator Skill	Average	Poor	Good	Good
Angle of Swing	160	170	150	80
Height of Cut	1 m.	1.5 m.	2 m.	1.5 m.
Fill Factor	1.05	1.05	1.05	1.05
Swell Factor	20	20	20	25
Efficiency	0.74	0.67	0.67	0.84
Condition of Equipment	Average	Good	Good	Good

Factors	Site 10	Site 11	Site 12	Site 13
Type of Soil	Wet Black Cotton Soil	Wet Clay and Boulders	Wet Gravel	Wet Gravel
Bucket Capacity	0.92	0.9	0.9	1
Cycle Time (Theoretical)	15	15	15	15
Cycle Time (Recorded)	27	23	17	23
Production (by Theoretical Time)	120.21	112.56	88.86	165.78
Production (by Recorded Time)	66.78	73.40	78.40	108.12
Operator Skill	Very Poor	Very Poor	Average	Good
Angle of Swing	180	180	130	90
Height of Cut	2 m.	0.5m	0.5 m.	2.5 m.
Fill Factor	1.05	1.05	0.7	1.05
Swell Factor	35	35	14	14
Efficiency	0.7	0.67	0.67	0.75
Condition of Equipment	Good	Good	average	Average

VI. RESULT AND DISCUSSION

It was observed that average cycle time for the excavator is 21.30 seconds, whereas theoretical value provided by handbook for 0.9 m3 bucket excavator is 15 seconds. The average swing time for an empty bucket is 5.03 (23.61 %) seconds . the machine needs 7.13 (33.48 %) seconds to fill the bucket. The average swing time for the full bucket is 6.32 (29.67 %) seconds. It takes the excavator 2.82 (13.24 %) seconds to dump the load.

Hoe productivity as it relates to cycle times, it is possible to gain a second here and a few milliseconds there, but if the excavator does not have the operator trained properly then all the efforts are wasted.

Data obtained by monitoring the machine during a regular operation period shed a light on machine operation and contribute towards the development of the performance and duty monitor for large hydraulic excavator.

Putting back the truck in the right position also saves time for the excavator operator.

If the backhoe is set up correctly with the truck on the lower level with the bucket racking up the face and a low swing angle 30o to 50o, the cycle time could as little as 10 to 12 seconds. With the truck at the upper level, it's not nearly as efficient.

Following graphs show how the Actual production varies from the production by theoretical formula and how the operator skill and angle of swing to dump the load affects the production.

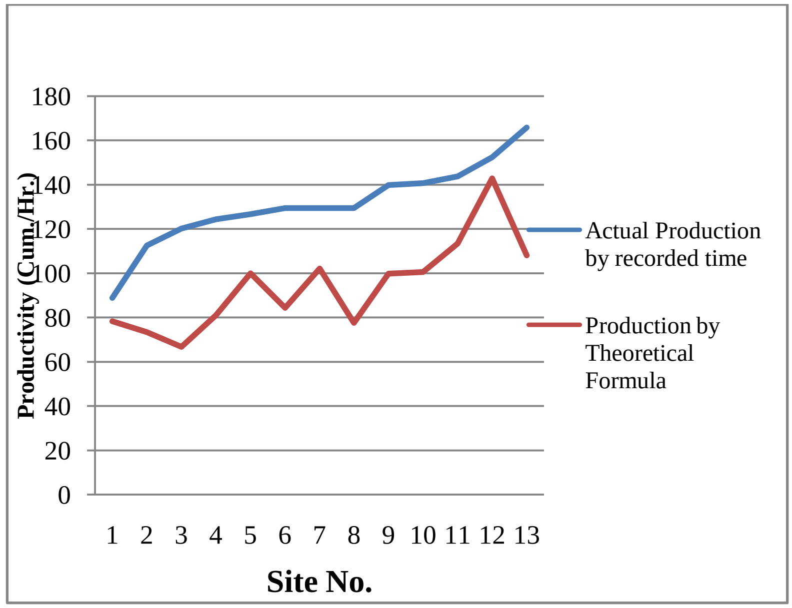

Fig. 1 Graph Showing Theoretical Productivity and Production by Recorded Time

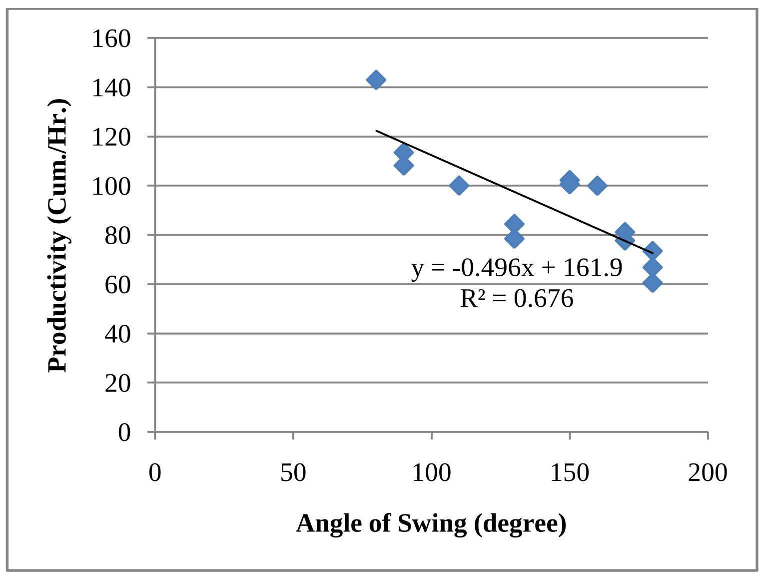

Fig. 2 Graph Showing Relationship Between Productivity and Angle of Swing

Relative Importance Index (RII) of different factors by on-site observations and by taking opinions of related Engineers and Managers is also determined to find out the relative importance of factors that influence the performance of excavator. The RII was used to rank those different factors which made it possible to cross compare the relative importance of those factors.

TABLE IV

Relative Importance Index

Factors	Rank
Operator Skill	1
Avaibility of Hauling Units	2
Soil conditions	3
Bucket Size	4
Cycle Time	5
Machine Conditions	6
Height of Cut	7
Angle of Swing	8
Dumper Position	9
Environmental Conditions	10

The Production Performance ratios are calculated by volume of per operator hour i.e. corresponding actual productivity, by the estimated productivity.

TABLE V

Production Performance Ratios

Site No.	Actual Capacity	Estimated Productivity	Production Performance Ratio
1	143.64	113.4	0.789
2	140.7	100.5	0.714
3	124.32	81.08	0.652
4	126.63	99.97	0.789
5	129.3	84.36	0.652
6	139.86	99.9	0.714
7	129.44	77.66	0.60
8	129.44	102.2	0.789
9	152.40	142.88	0.937
10	120.21	66.78	0.555
11	112.56	73.40	0.652
12	88.86	78.40	0.882
13	165.12	108.12	0.654

There are no reasons to suspect the production motivation for the operators of any particular equipment type differs from the others, since operators of all types are producing under almost the same Production incentive system. Therefore the variation in the Production performance Ratio from one equipment type to another may be due to the differences in the operator's Skills.

VII. CONCLUSION

Hydraulic backhoe was selected for the study because the equipment is the major source in most of the earthmoving operations in the construction industry. Based on the study the following conclusions could be drawn.

The average actual production for the 0.9, 1 & 1.2 cum. bucket capacity could be considered as 28% less than the estimated hourly earthwork production mentioned in the handbook.

The loss of productivity for the equipment in the study is indicated by values, which ranged from a maximum of 0.55 for excavators down to 0.93.

The overall value of Production Performance ratio averages 0.72 for all the equipment in the study. This is relatively low Production Performance ratio value that indicates poor production per hour.

The actual excavator cycle time could be considered as 25 to 28 % higher than estimated cycle time if the dumper is not properly positioned.

The most commonly used bucket size for the excavation activity is of 0.9 cum. capacity.

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