Improvised Scheduling Framework Integrating WS, MS, & DS for Repetitive Construction Projects

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ABSTRACT

There is acute shortage of skilled worker globally against increasing demand of infrastructure, changing work cycle; absenteeism, etc. Mechanisation, automation, and several approaches have been attempted to overcome this shortage that resulted in marginal improvements. The primary reason for this can be attributed to insufficient coordination among key stakeholders. To improve the project performance, a frame work for improvised schedule is proposed combining Work Study (WS), Multi Skilling (MS) and Dynamic scheduling (DS). This approach is expected to show improvement at three stages: 1) At activity level by simplification of basic execution processes through work study, 2) At crew level by optimally utilising multi skilled workers with varying degree of proficiency, and 3) At project level through smooth execution of activities by dynamic workers allocation. This approach was experimented on mass housing project and the initial results were reviewed with experts. Repetitive construction project was primarily chosen for this study owing to simplicity and fast learning due to crew continuity. Expert's feedback along with the applicability of this framework is also discussed in this paper.

Keywords –

Work Study; Multi Skilling; Dynamic Scheduling; and Repetitive Construction Project.

1 Introduction

Researchers have identified that project performance can be improved through close coordination among the key stake holders i.e. customer, contractor and consultant through shared goal [8]. The lack of consensus among key stake holders is one of the main causes behind time-cost overrun in construction projects which most often results into unrealistic scheduling and inefficient utilisation of scarce available skilled workers. If project goal could be identified through consensus among key stakeholders, there could be many ways to improve the project performance through standardisation, mechanisation, automation, etc.

In this study, improvement in project performance has been attempted by integrating three approaches, i.e. work study (WS), multiskilling (MS) and dynamic scheduling (DS). The WS, invariably investigated for productivity improvement [4] [10], has been utilized to define basic processes, baseline productivity and improve method of execution. To overcome the known flaws of inefficient resource utilization, specifically the worker force, multi-skilling strategy is deployed. DS is considered to determine a realistic schedule factoring numerous uncertainties and opportunities encountered during planning and execution.

Thus, the objective of the present study is to determine an improvised schedule utilizing WS, MS and DS for repetitive construction projects. The authors had chosen repetitive construction projects as it is reliable for better results than non-repetitive construction projects. Given the background of the study, this paper is organized as follows: The framework for the improvised schedule is elaborated in the next section followed by the case illustration. The observations and results of the case are presented in the subsequent section followed by discussions.

2 Proposed Solution Framework

A frame work combining shared goal, constraints, key stake holders and approaches to achieve the shared goal has been represented as shown in figure 1. It is well-known that time; cost and quality are the key parameters to measure project success [1][2]. Variations to these parameters are generally induced by three key stake holders; (1) customer who defines functional requirement; (2) contractors who execute the work and (3) consultant who defines technical specification and corresponding cost. All these participants have individual objectives which may be conflicting in nature and thus they form the boundary of the iron triangle as seen in the figure 1.

Figure 1. Proposed framework to improve project performance

There could be many approaches to improve these parameters and to balance the benefits induced by the stakeholders. In the present study, WS, MS and DS are planned to define the project success in the context of proposing an improvised schedule that remains relevant throughout project execution. It is envisaged that WS [4] can improve the project performance at activity level; MS [3] which can improve the workers utilization [6][7] and DS [5] can bring changes to the project duration through better coordination among activities. This attempt was initially experimented on repetitive projects due to the simplicity of repeating activities.

The activities of a repetitive construction project can be broadly divided into repetitive and non repetitive activities. In case of mass housing project repetitive activities include construction of Dwelling Units (DUs) whereas non repetitive activities include preparatory work (i.e site office, labour camp, site clearance, setting out, site laboratory, concrete batching plant etc) and external services (i.e road, external water / electric supply, sewage etc). Since, major effort goes into construction of DUs, the focus of the present study is limited to the scheduling of repetitive units. Integration with non repetitive activities have been discussed at the end of this manuscript. The methodology for the scheduling framework comprising of WS, MS and DS in respect of repetitive construction projects has been elaborated in the flow diagram given in figure 2.

As seen in the flow diagram initial project schedule can be generated using DUs construction data. By analysing initial schedule, few important activities from several critical activities can be identified based on dual criteria, 1) Reduction in activity duration results into maximum reduction in overall project duration, and 2) Feasibility of improvement through WS. Having identified important activities, WS can be performed and revised duration of important activities can be utilised. In addition, multi skilled workers can be utilised to reduce the fluctuations in the workers demand. Having met the requirement of workers for repetitive unit construction, remaining workers can be efficiently employed using resource constrained project scheduling. The revised schedule can be further improved through DS by changing type of buffer (i.e end type to start type), shifting of crew during absenteeism, etc. The entire concept has been explained through a case study given in the next section.

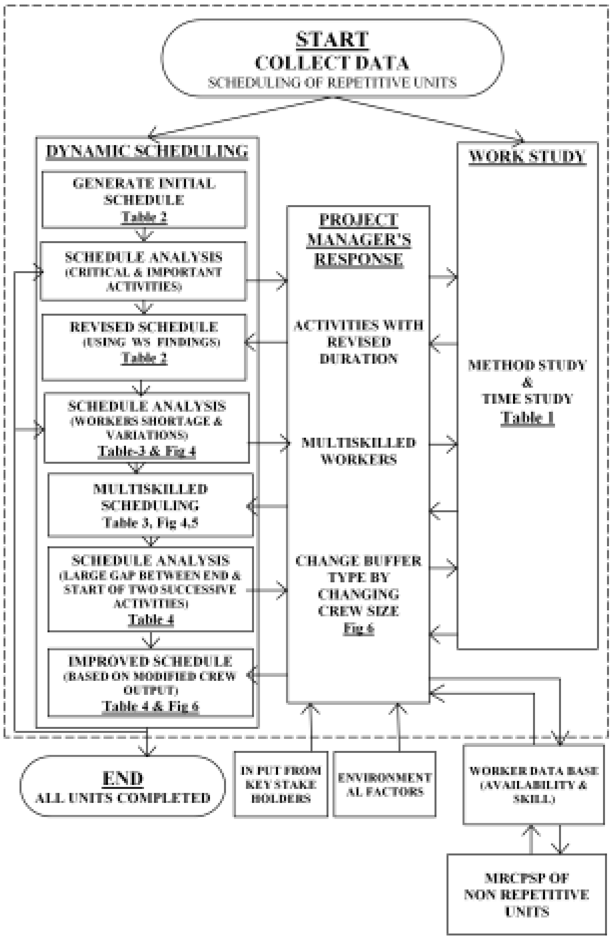

Figure 2. Proposed framework to improve project performance

3 Case Illustration

As mentioned earlier, data has been collected from the mass housing project to illustrate the improvement in scheduling. The layout of housing project is given as figure 3. The scope of project includes construction of

50 blocks of married accommodation having 4 DUs in each block with G+1 configuration. The project Phase 1 (i.e Utility building and two blocks) has to be completed in 14 months and entire project in three years.

There was complete lack of co-ordination among contractor, user and consultant. Initially site for two blocks and for utility building was given to contractor. The remaining site was not available due to lack of clearance from state electricity department whose high tension line was passing through the site. There was delay in approval of design mix by consultant, and the work progress was much slower than expected specially reinforced cement concrete (RCC) work. The project schedule prepared by the contractor depicted each married accommodation block as one unit without any further breakdown.

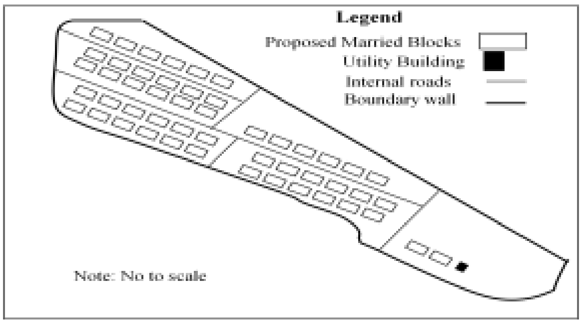

Figure 3. Proposed framework to improve project performance

3.1 Initial & Revised Schedule through WS

Having presented the overall project details in the earlier section, this section elaborates the WS part. The work study revealed maximum inefficiency in cutting, bending & placing of rebars in roof beams and slabs. Introduction of automatic bar bending and cutting machine coupled with improved method of execution had reduced the crew size as well as time of execution for the utility building as seen in table 1 (interested authors can refer to [9] for details).

Since, major effort was required in construction of repetitive units (DUs), a detailed schedule for repetitive units ensuring crew continuity was essential. To prepare initial schedule, series of 57 distinct activities involved in execution of one block (4 DUs) were listed. Quantum of work for each activity was calculated using architectural and structural drawings. The requirement of workers for each activity was obtained from the experts (i.e site in charge, resident engineer, labour contractor and junior engineer). Having removed inconsistent input, average requirement of the workers was worked for each activity. The activities were planned to be executed in sequence (all activities critical) with one day buffer between each activity was enforced. The initial schedule meeting project deadline was prepared using Line of Balance Technique (LOB). Partial snapshot of the entire calculations are presented in table 2 and it can be seen that duration to complete one block was 396 days and overall project duration was estimated at 1042 days.

Table 1. Crew requirement before and after WS

Remark	Activities	Highly Skilled	Skilled	Semi Skilled	Helper	No of Days
Output data taken from published case study [9]	Before WS - Utility Building Slab - 51sqm					
	Cutting & Bending		2		4	18
	Placing		1		2	15
	After WS - Utility Building Slab - 51sqm					
	Cutting & Bending		1		2	14
	Placing		1		2	10
Input data for floor slab (activities 19 & 20 of table 2)	Before WS - Floor Slab - 388sqm					
	Cutting & Bending	1	8	8	2	**18**
	Placing	1	8	8	2	**8**
	After WS - Floor Slab - 388 sqm					
	Cutting & Bending	1	8	8	2	**7**
	Placing	1	8	8	2	**5**
Input data for roof slab (activities 31 & 32 of table 2)	Before WS - Roof Slab - 322 sqm					
	Cutting & Bending	1	8	8	2	**5**
	Placing	1	8	8	2	**6**
	After WS - Roof Slab - 322 sqm					
	Cutting & Bending	1	8	8	2	**6**
	Placing	1	8	8	2	**4**

With the published data available for cutting, bending and placing of reinforcement of the utility building, the duration of 4 activities (i.e 19, 20, 31 and 32) for the ground floor (size 388 sqm) and first floor slab (size 322 sqm) was calculated and is shown in table 1. This modified duration of the above four activities resulted into considerable reduction in project duration from 1042 days to 926 and is portrayed in table 2. Considering the high overhead cost, this saving of 116 days is of great significance. Once the activities have been improved through WS, crew level alterations were attempted through MS and are discussed in the subsequent paragraphs.

Table 2. Scheduling Using LOB (Before and after Work Study)

	Activity No	**Activity**	High Skilled	Skilled	Semi Skilled	Helpers	Activity Time	Crew deployed	Buffer		Start Date	
									Type	Duration	1st Unit	Last Unit
SCHEDULE BEFORE WORK STUDY	1	Digging using JCB	1	0	1		2	1	S	1	1	99
	19	**Cutting & Bending Rebars for Floor Beam & slab**	1	8	8	32	**18**	**4**	**S**	**1**	**266**	**486**
	20	**Placing of Rebars for Floor Beam & Slab**	1	8	8	32	**8**	**3**	**S**	**1**	**285**	**415**
	21	Approval of Rebars	1			1	1	1	E	1	375	424
	22	Casting of Floor Beam & SLAB	2	13	13	56	1	1	S	1	377	426
	23	Curing 14 Days			1	1	14	7	S	1	379	477
	24	Cut & Bend Rebars for Column Including Lintel Beam at 1st Floor	1	7	7	28	8	4	S	1	394	492
	25	Shuttering of Column up to & including Lintel Beam	1	2	3	6	6	3	S	1	403	501
	26	Casting of Column up to & including Lintel Beam	1	1	2	8	3	2	E	1	435	508
	27	Shuttering for Column up to Roof Beam	1	2	3	12	1	1	E	1	463	512
	28	Cutting, Bending & Placing Rebars for Column up to Roof Beam	0	5	5	10	2	1	S	1	465	563
	29	Cast Column up to Roof Slab		1	1	4	1	1	E	1	517	566
	30	Shuttering Roof Beam & Slab	1	2	3	12	9	5	S	1	519	607
	31	**Cutting & Bending Rebars for Roof Beam & slab**	1	8	8	32	**15**	**3**	**S**	**1**	**529**	**774**
	32	**Placing of Rebars for Roof Beam & Slab**	1	8	8	32	**6**	**2**	**S**	**1**	**546**	**693**
	57	Site clearance	**1**			**10**	6	3	S	0	939	1037
	PROJECT DURATION IN DAYS											**1042**
SCHEDULE AFTER WORK STUDY	1	Digging using JCB	1	0	1		2	1	S	1	1	99
	19	**Cutting & Bending Rebars for Floor Beam & slab**	**1**	**8**	**8**	**32**	**7**	**4**	**E**	**1**	**268**	**354**
	20	**Placing of Rebars for Floor Beam & Slab**	**1**	**8**	**8**	**32**	**5**	**3**	**E**	**1**	**280**	**362**
	21	Approval of Rebars	1			1	1	1	E	1	319	368
	22	Casting of Floor Beam & SLAB	2	13	13	56	1	1	S	1	321	370
	23	Curing 14 Days			1	1	14	7	S	1	323	421
	24	Cut & Bend Rebars for Column Including Lintel Beam at 1st Floor	1	7	7	28	8	4	S	1	338	436
	25	Shuttering of Column up to & including Lintel Beam	1	2	3	6	6	3	S	1	347	445
	26	Casting of Column up to & including Lintel Beam	1	1	2	8	3	2	E	1	378	452
	27	Shuttering for Column up to Roof Beam	1	2	3	12	1	1	E	1	407	456
	28	Cutting, Bending & Placing Rebars for Column up to Roof Beam	0	5	5	10	2	1	S	1	409	507
	29	Cast Column up to Roof Slab		1	1	4	1	1	E	1	461	510
	30	Shuttering Roof Beam & Slab	1	2	3	12	9	5	S	1	463	551
	31	**Cutting & Bending Rebars for Roof Beam & slab**	**1**	**8**	**8**	**32**	**6**	**3**	**S**	**2**	**473**	**571**
	32	**Placing of Rebars for Roof Beam & Slab**	**1**	**8**	**8**	**32**	**4**	**2**	**S**	**1**	**481**	**579**
	57	Site clearance	**1**			**10**	**6**	3	S	0	823	921
	PROJECT DURATION IN DAYS											**926**

3.2 Multiskilling

Although there are 57 activities, only 10 types of crews are required. The number and type of crews required on any day can be obtained as start and end of each activity and number of crew required for each activity is known (Table 2). The summary of workers requirement in respect of selected trades where multiskilling is feasible has been presented in table 3. The analysis of workers requirement revealed wide fluctuation in workers of different trade over the entire project duration. Since, there are practical difficulties in hiring and firing the workers depending upon the actual project requirement on a particular day in addition to the associated cost, multi skilled crew and multi skilled workers can be employed. This has the potential to reduce fluctuation and increase duration of employment of multiskilled workers. This strategy was proposed in two options: 1) A multi skilled crew which can perform two types of activities; 2) Set of multiskilled workers who can be part of different crew depending on the requirement on a given date and is elaborated in the forthcoming paragraphs.

Table 3. Impact of Multiskilling on Workers Employment

Employment of Workers without Multi Skilling					
Workers Required	**Shuttering**	**Carpenter**	**Barbender**	**Mason**	
Average	18.6	27	76.3	41.8	
Median	18	18	67	38	
Highest	48	67	143	143	
Minimum	12	14	2	2	
Standard Deviation	8.2	17.9	31	31.9	
Days Employed	545	327	573	816	
Employment of Workers with Multi Skilling					
Workers Required	**MS type 1**	**Barbender**	**Mason**	**MS Type 2**	**Surplus MS type-2**
Average	22	55.2	19.8	36.7	-11.1
Median	18	47	6	38	-8
Highest	67	113	107	38	-18
Minimum	12	0	0	23	-6
Standard Deviation	13.7	28	26.1	4.2	4.5
Days Employed	912	571	664	864	28

3.2.1 Multi skilled Crew (MS Type-1)

It is a well-known fact that the task of shuttering and carpenter is similar to certain extent. A crew with mutliskilled workers who can perform both the task will enhance employment duration and reduce uncertainty. As seen in table 3, the duration of employment for shuttering crew was 545 and carpenter was 378. When multiskilled crew capable to execute both tasks were employed, the duration of employment increased to 912. The average requirement of workers was 22 which are higher than the individual shuttering and carpenter crew of 18.6 and 18 respectively. The reduction in standard deviation confirms lesser variation in employment numbers (Table 3). This is also presented graphically in figures 4 & 5.

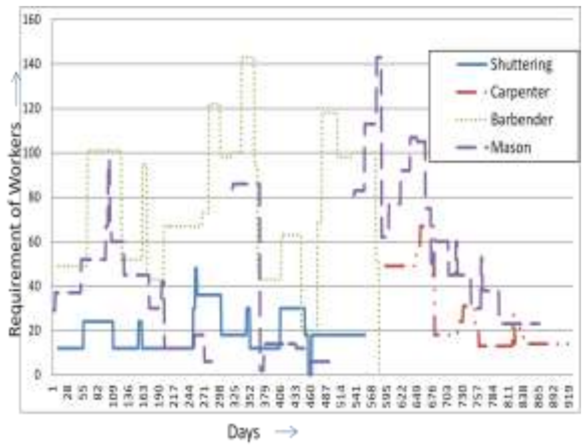

Figure 4. Workers demand without multiskilling

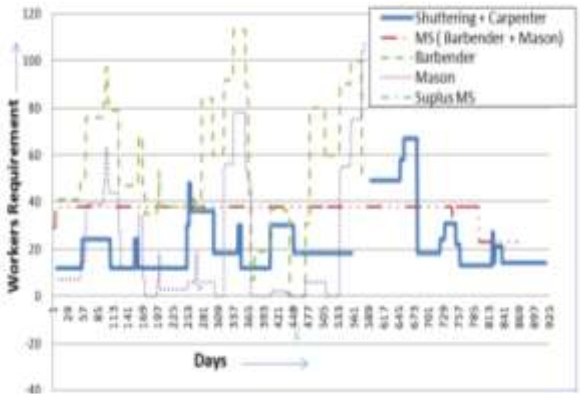

Figure 5. Workers demand with multiskilling

As seen in Table 2, MS Type-2 (38 numbers equal to lower of the median of mason & barbender) gets employment longer than even mason (i.e 864 days against 816 days). The use of MS Type-2 also reduces requirement of single trade crew. As seen in Table 4, the requirement of Mason crew reduces to 664 days from

816 days and Barbender crew from 573 to 571. Judicious employment of MS Type-2 also reduces the fluctuation in workers demand with single trade. As it can be seen in Table 3, standard deviation of Barbending crew reduces from 31 to 28 and standard deviation of Mason crew reduces from 31.9 to 26.1 and is also seen in figures 4 & 5**.**

3.2.2 Multi skilled Worker (MS Type 2)

Other approach could be use of a percentage of multiskilled workers (Barbender cum Mason) along a single trade crew (Barbender/Mason). Logically concreting commences after reinforcements are in place. For example, a bar bender working on concreting will ensure that reinforcement is not disturbed and rectify the spacing if concrete is not able to go inside structural members due to excessive reinforcement, by adjusting the location of splice or informing the engineer to increase the size of bars with corresponding reduction in numbers. To avoid idle bar benders, few barbenders can be trained for concreting operations. These MS Type-2 workers will have longer employment and will make positive impact on quality of work as well.

3.3 Dynamic Scheduling

The project performance can be improved further by changing the type of buffer in respect of selected activities. As seen in Table 4 there is a large gap between activities 10, 11 and 15, 16. The increase in slope of activity 10 & 15 by deploying more workers can alter the gap as shown in figure 6.

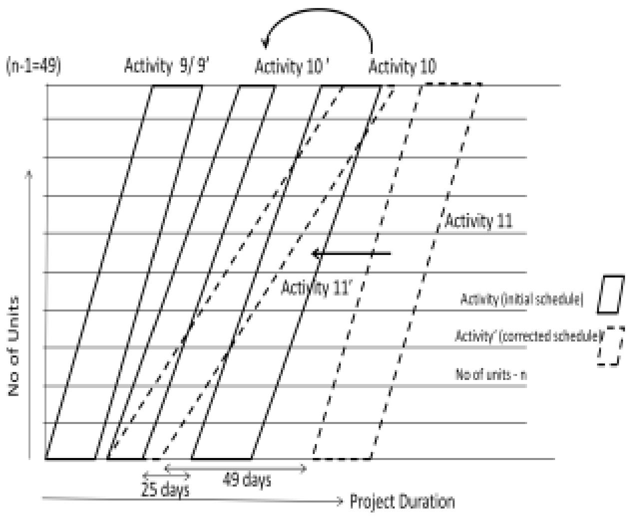

Figure 6. Shift in activity start time with end type buffer

As seen in the Table 4, reduction in duration of activity 10 and 15 from 2 days to 1 day reduces the gap between start of activity after predecessor activity from 49 to 25 and further reducing the project duration from 926 days to 875 days without increase in required man-days. The overall results are discussed in the next section.

4 Discussions & Summary

The combination of WS, MS and DS were beneficial in improving project performance of repetitive construction through reduction in project duration from 1042 days to 875 days with marginal fluctuation in workers allocation.

As seen in the case study, application of improvised scheduling is complex process. In the present study, problem has been simplified to certain extent by limiting the scope of application to repetitive units of mass housing project.

In this study LOB has been used. However, use of LOB will be further complex in case of repetitive units with large number of activities having varying buffers, numerous concurrent activities, activities execution with lead or lag etc. Study on schedule adjustment using suitable software can be beneficial and research work in this area is under progress.

As seen in Table 3, there is wide fluctuation in the requirement of workers despite use of multiskilling. Hiring and leaving workers on regular basis is not practical and hence optimum number of workers has to be worked out with gradual increase/decrease pattern. However this will result into surplus workers of different skills and trades not employed on repetitive unit construction on a given date. Despite resource levelling, the variation can remain with workers of different trades. These surplus workers could be effectively absorbed using resource constrained project scheduling of non repetitive units like preliminary activities and external services etc. Hence there is need for integration of two schedules with common workers pool as presented in generic methodology in figure 2.

In this study DS scheduling is used to change the type of buffer with the aim to reduce project duration. Additionally, DS can be used whenever activity duration changes (i.e due to change orders, learning curve of workers, etc) or crew availability changes (i.e due to absenteeism, emergent demand in other non repetitive critical activity, etc). Similarly multiskilling can be attempted after every change in the schedule for optimum utilisation of workers which will definitely benefit the industry. This is definitely a scope for future work.

Table 4. Dynamic Scheduling using LOB

	Activity No	Activity	Highly Skilled	Skilled	Semi Skilled	Helpers	Activity Time	Crew Required	Buffer Type	Start Date		Delay in Start
										1^{st} Unit	Last Unit	
Schedule After Work Study	1	Digging using JCB	1	0	1		2	1	S	1	99	
	2	Digging Manual	1	0	4	24	2	1	S	4	102	0
	3	Plain Cement Concrete Bed	1	1	1	5	2	1	S	7	105	0
	4	Shuttering for Foundation	1	2	3	6	2	1	S	10	108	0
	5	Cut, Bend & Place Rebars for Foundation	1	8	8	32	14	7	S	13	111	0
	6	Foundation Concreting	1	2	2	10	3	2	E	53	126	25
	7	Shuttering for Column & Plinth Beam (PB)	1	2	3	6	6	3	S	57	155	0
	8	Cut, Bend & Place Rebars for Column & PB	1	8	9	34	8	4	S	64	162	0
	9	Concreting for Column upto & Including PB	1	2	2	10	3	2	E	97	171	25
	10	**Earth Filling Under Floor**	**1**	**2**	**8**	**48**	**1**	**1**	**E**	**126**	**175**	**25**
	11	**Anti Termite Treatment**	**1**	**0**	**2**	**2**	**1**	**1**	**S**	**128**	**177**	**0**
	12	Shuttering Column upto & Including Lintel Beam (LB)	1	2	3	6	6	3	S	155	253	0
	13	Cut, Bend & Place Rebars for Column Including LB	1	7	7	28	8	4	S	162	260	0
	14	Casting Of Column up to & Including LB	1	1	2	8	3	2	E	196	269	25
	15	**Cut, Bend & Place Rebars , Column & Floor Beam**	**1**	**2**	**12**	**12**	**2**	**1**	**S**	**200**	**298**	**0**
	16	**Shuttering For Column up to Floor Beam (FB)**	**1**	**2**	**3**	**12**	**1**	**1**	**E**	**252**	**301**	**49**
	57	Site Clearance	1			10	**6**	3	S	823	921	0
		PROJECT DURATION IN DAYS									**926**	
Schedule After Work Study & Dynamic Scheduling	1	Digging using JCB	1	0	1		2	1	S	1	99	
	2	Digging Manual	1	0	4	24	2	1	S	4	102	0
	3	Plain Cement Concrete Bed	1	1	1	5	2	1	S	7	105	0
	4	Shuttering for Foundation	1	2	3	6	2	1	S	10	108	0
	5	Cut, Bend & Place Rebars for Foundation	1	8	8	32	14	7	S	13	111	0
	6	Foundation Concreting	1	2	2	10	3	2	E	53	126	25
	7	Shuttering for Column & PB	1	2	3	6	6	3	S	57	155	0
	8	Cut, Bend & Place Rebars for Column & PB	1	8	9	34	8	4	S	64	162	0
	9	Concreting for Column upto & Including PB	1	2	2	10	3	2	E	97	171	25
	10	**Earth Filling Under Floor**	**1**	**2**	**8**	**48**	**2**	**1**	**S**	**101**	**199**	**0**
	11	**Anti Termite Treatment**	**1**	**0**	**2**	**2**	**1**	**1**	**E**	**153**	**202**	**49**
	12	Shuttering Column upto & Including LB	1	2	3	6	6	3	S	155	253	0
	13	Cut, Bend & Place Rebars for Column upto & including LB	1	7	7	28	8	4	S	162	260	0
	14	Casting Of Column up to & Including LB	1	1	2	8	3	2	E	196	269	25
	15	**Cut, Bend & Place Rebars , Column up to FB**	**1**	**2**	**12**	**12**	**2**	**1**	**S**	**200**	**298**	**0**
	16	**Shuttering For Column up to FB**	**1**	**2**	**3**	**12**	**1**	**1**	**E**	**252**	**301**	**49**
	57	Site Clearance	1			10	**6**	3	S	772	870	0
		PROJECT DURATION IN DAYS									**875**	

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