Computation of material and labour inputs for office buildings

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An estimate of the quantum of manpower and materials required for the construction of buildings is often necessary before starting construction. Calculations for important materials and labour are usually based on rough norms, or percentages which are sometimes misleading. The method of preparing detailed bills of quantities and then calculating the requirements with the aid of analysis of rates, though ideal, is time consuming. Studies have been made at the Central Building Research Institute to formulate quick estimates of materials/labour in the form of simple equations. The paper discusses the norms used in calculating the cost index which is described with the help of an example of an office building.

An estimate of manpower and materials is generally required for projects prior to the start of actual construction for purposes of budgeting, calculation of cost index, justification of tenders, etc. Computation of quantities of important materials and labour charges is usually based on the percentage of total cost of building which an individual material or category of labour will use up.

This method may not give realistic results because these percentages are usually assumed to be same for all types of buildings, which is not true; also these may vary from time to time and place to place depending upon the market prices of various items. The other method of computation of the quantities is to prepare a detailed estimate/bills of quantities and then calculate requirements with the aid of material and labour constants usually taken from an analysis of rates. This method, though ideal, is very time consuming and also requires complete set of drawings, designs and other details in advance, which are not usually available. An attempt was made sometime back at the Central Building Research Institute to develop the required information for residential buildings in the form of graphs and equations in order to arrive at the results with ease and sufficient accuracy. This has proved to be quite useful for quick estimates and is being used by a number of individuals and organisations. It is a matter of fact, that apart from the specifications, materials and labour required depend upon the physical planning, shape, height, fenestration etc., of the buildings and that buildings other than residential buildings depending on their end use will differ in all these aspects; *e.g.* residential, commercial, industrial. Therefore, a separate study was required for non-residential buildings. This paper describes the work done for office buildings, which form a major portion of the construction activity in the country. The present study is applicable to office buildings with plinth area varying from 1,600 to 26,000 m² and ranging from 4- to 10-storey framed structure.

Basis of calculations

The basic requirement for the study is to know the exact quantum of materials and labour which has been actually used for completion of various projects with varying plinth areas so that the consumption of each material/labour can be related to a range of plinth area. In order to arrive at an accurate consumption of materials/labour, the analysis has been based on the final bills of completed buildings. The final bills have been preferred to the estimated quantities because there is always fluctuation between the estimates and the final quantities. It was, therefore, considered to be more logical to base the study on the final bills rather than estimates. The final bills were collected from various organisations such as CPWD, PWD, Delhi Administration, BHEL at Hardwar, and CSIR at New Delhi.

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It was seen from the data that all the office buildings were framed structures ranging from four to ten storeys with total plinth area varying from 1,600m² to 26,000m². In order to have consistency in the study, the best alternative was to establish relations separately for buildings with varying numbers of storeys; *i.e.* classify buildings according to the number of storeys they carry. But due to difficulty in getting sufficient data for each category of building (storeywise) separate sets of relations were not feasible, so a single set of relations has been established after making adjustments in some of the elements like foundation, roofing, etc.

Specifications and computation

The requirement of materials and labour mainly depends upon the specifications, shape and storey height apart from the size of the building. The survey of the final bills revealed that sometimes different specifications were adopted for the same element of the building in different projects. To overcome this non-uniformity, a set of reference specifications was prepared based on the specifications which were most commonly used in various buildings. The practice likely to be followed in the future construction works was also kept in view. The data were adjusted to these specifications and computations made accordingly. The reference specifications adopted are shown in *Appendix* 1.

The shape of the building may also have some effect on the consumption of materials and labour in a building. The major effect with the change of shape is on the walling element. This factor has been taken care of by considering a number of buildings with different configurations so as to give a fairly average consumption. With regard to the effect of the storey height, again the walling as well as foundations are the main elements which are affected so far quantities of materials/labour are concerned. It was seen from the details of the data that the storey height normally varied from 3.05m to 3.20m in various projects indicating that there was a difference in storey height to the extent of only 15cm. No adjustment has therefore been made in this regard as no major effect is contemplated.

There may be different types of foundations for a structure depending upon the nature of soil and bearing capacity, load and types of the structure. Two types of foundations, namely column footings and raft foundation were noticed in the data and these were considered in the study. Computation for the statistical relations were based on the column footings and the additional quantity of reinforced concrete work, including reinforcement was calculated, in case, the raft foundation had to be adopted. As mentioned earlier a single set of relations was established irrespective of the number of storeys in the buildings, so the roof treatment remains constant for the buildings with same plinth area at ground floor, whether it is a four-storey building or a ten-storey

buildings. In view of the above, there will not be proportional distribution of materials and labour of roof work. Hence, it was decided that the roof treatment should be omitted altogether in order to avoid this discrepancy.

In the case of reinforcement, it was observed that in most of the buildings mainly deformed bars had been used. The computations were made on the assumption that the total reinforcement was in the form of deformed bars. However, the requirement of mild steel was also given in terms of percentage of the total reinforcement.

Statistical relations

The quantities of various items of works were collected from the final bill of each building. Each item of work was then analysed in terms of materials and labour with the help of CPWD rates. Then the similar materials and labour were synthesised in order to arrive at the total consumption of material and labour separately for each building. This exercise was done for all the buildings having different plinth areas. This analysis revealed the comparative consumption of each material and labour in different buildings. Based on the quantities computed for these buildings with different plinth areas, relationships were established statistically for each material/category of labour against the plinth area of these buildings. In all, relations for 21 materials and six categories of labour have been established which are applicable for plinth area ranging from 1,600m² to 26,000m². These relations are given in *Table* 1. The requirement of any material/labour can be computed by putting the total plinth area, A (plinth area of all the floors of the building) in the equation. The relations have been given only for the important materials/labour which constitute the major portion of the building cost. As mentioned earlier, the type of foundation considered in the study is column footings. In case of raft foundation, additional quantities; *i.e.* 10m³ of reinforced concrete work alongwith 1.2t of reinforcement per 100m² of plinth area be added.

No attempt has been made to derive relation for rain water pipes and door and window fittings. However, one 100-mm diameter rain water pipe with necessary accessories may be taken for 40m² of roof area according to Indian Standard *Code of practice for laying lime concrete for waterproofed roof finish*, IS: 3036-1965. To count towards the cost of door and window fittings, either a lump sum amount may be added, or the actual number of fittings may be calculated based on the number of doors and windows in the building. This is elaborated in *Appendix* 2. Certain items such as centering, shuttering and scaffolding do not form part of the building but are essentially required during the course of construction. As far as centering and shuttering is concerned, the requirement of timber and ballies has been given in the form of relations, *Table* 1. For scaffolding, the labour contents involved have been reckoned in these relations but materials have not been taken into account due to its complexity in use. The cost of materials may be added either on the basis of percentage of the total cost of building or lump sum amount may be considered while computing the cost of the building.

Uses

The study is useful for quick estimation of materials/labour which can be made use of for material budgeting, justification of tenders, calculation of cost indices, computation of building cost, etc. To illustrate the above uses, quantities have been worked out for a five-storey building with 10,000m² total plinth area. This is shown in *Appendix* 2. Such computations can serve as a useful guide to the owner/builder for budgeting and procurement of materials. The same calculations may be used for the purpose of justification of tenders. For this, the important materials and labour may be priced at the rates which were prevalent at the estimate stage and also at the prevailing market rates. From the ratio of the two, the actual increase/decrease in building cost can be calculated and compared with the tendered percentage, on or off the estimated cost. For computation of building cost all the materials and labour thus calculated may be priced with the current market rates. Provision should also be made for the cost of rain water pipes, door and window fittings, scaffolding, water charges and contractor's profit and overheads. The calculations are based on rates in Roorkee and are illustrated in the *Appendix* 2, which is self-explanatory. The plinth area rate works out to be Rs 613/m² which is in conformity with the one prevalent in Roorkee. Computation of cost indices has also been shown in *Appendix* 3. The cost index at Roorkee for the year 1980 has been worked out with the base year 1977 at Roorkee. Only important materials and labour need be considered for computation of cost indices.

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TABLE 1 Statistical relations for 1600m² to 26000m² plinth areas

Serial no	*Materials/Labour*	*Unit*	*Statistical relations*
1.	cement	tonnes	$0.1925A + 18.52$
2.	fine sand	m³	$0.08A + 105.50$
3.	coarse sand	m³	$0.2592A - 80.94$
4.	20-mm coarse aggregate	m³	$0.2728A - 48.50$
5.	10-mm coarse aggregate	m³	$0.1164A - 20.74$
6.	40-mm coarse aggregate	m³	$0.0151A + 73.91$
7.	25-mm brick ballast	m³	$0.0426A - 38.37$
8.	timber for formwork	m³	$0.005A + 11.19$
9.	timber for joinery	m³	$0.0024A - 0.53$
10.	ballies	m	$0.5507A + 797.50$
11.	bricks	'00	$1.1829A - 524.23$
12.	deformed bars	tonnes	$0.0479A$
13.	door shutters	m²	$0.0636A - 17.07$
14.	window shutters	m²	$0.1117A + 93.26$
15.	glass	m²	$0.1407A + 55.99$
16.	primer	lit	$0.0256A + 9.70$
17.	paint	lit	$0.0322A + 7.24$
18.	lime	quintals	$0.0754A - 51.21$
19.	surkhi	m³	$0.0204A - 18.39$
20.	marble chips	quintals	$0.1338A - 48.52$
21.	marble powder	m³	$0.0012A - 0.36$
22.	mason	working days	$1.1314A - 407.40$
23.	carpenter	working days	$0.7094A + 449.09$
24.	glazier	working days	$0.0122A + 10.31$
25.	painter	working days	$0.0905A + 37.26$
26.	blacksmith	working days	$0.479A$
27.	beldar	working days	$6.055\ A - 2024.37$

Notes: (*i*) A is the total plinth area in m² of all the floors of the building
(*ii*) the type of foundation considered is column footings
(*iii*) the relation for reinforcement has been given in term of deformed bars; 10 to 20 percent of this reinforcement may be taken as mild steel

APPENDIX 1 Specifications

Serial no	Element/item of work	Reference specification adopted for the study
1.	Foundation	excavation in ordinary soil, reinforced concrete column footings with 1:5:10 plain concrete (cement: fine sand: graded stone aggregate, 40-mm nominal size) in beds
		sand filling in plinth under plain concrete beds
		brickwork in 1: 6 cement-mortar (cement: coarse sand) using traditional bricks
2.	Frame	reinforced cement concrete frame including finishing and plastering the exposed surface with 1:3 cement-mortar (cement: fine sand) of thickness not exceeding 6mm to give a smooth and even surface
3.	Walling	brick work in 1:6 cement mortar (cement: coarse sand) using traditional bricks
		half-brickwork in 1: 3 cement mortar (cement: coarse sand) with hoop iron reinforcement for partitions
		reinforced cement concrete work for lintels, chhajjas, fins including finishing and plastering the exposed surface with 1:3 cement mortar (cement: fine sand) of thickness not exceeding 6mm to give a smooth and even surface
4.	Flooring	terrazo (marble chips) flooring laid-in-situ, as follows: 100-mm 1:5: 10 thick plain concrete (cement: fine sand: graded stone aggregate 40-mm nominal size) sub-grade for ground floor and 50-mm thick cushioning layer of lime concrete using brick aggregate of 25-mm nominal size and 50 percent mortar comprising of 1 lime: 2 surkhi on reinforced concrete slab for upper floors
		40-mm thick marble chips flooring, machine rubbed and polished to granolithic finish underlayer 31mm thick 1:2:4 cement concrete (cement: coarse sand: graded stone aggregate, 10-mm nominal size) and top layer 9mm thick with marble chips laid in 3:1 marble powder mix (cement: marble powder) by weight in proportion of 4:7 (cement: marble powder mix: marble chips) by volume
		21-mm thick marble chips skirting rubbed and polished to granolithic finish under layer, 15mm thick 1:3 cement plaster (cement: coarse sand) and top layer, 6mm thick with marble chips laid in 3:1 cement marble powder mix (cement: marble powder) by weight in proportion of 4:7 (cement marble powder mix: marble chips) by volume
5.	Structural floor roof	reinforced cement concrete slab including finishing and plastering the exposed surface with 1:3 cement mortar (cement: fine sand) of thickness not exceeding 6mm to give a smooth and even surface
6.	Joinery	doors: wooden frames 100 × 60mm for doors with 40 × 3mm flat iron hold fast 400mm long and embedded in 1:3:6 concrete (cement: coarse sand: grade 300 × 100 × 150 mm block of stone aggregate 20-mm nominal size)
		35-mm thick flush door shutters, non-decorative type
		windows: steel glazed windows of standard rolled steel sections
7.	Finishes	white wash/colour wash internally and externally
		painting on doors and windows over a coat of primer.
		12-mm thick 1: 6 cement plaster (cement: fine sand) on smooth face of brick walls
		20-mm thick 1: 6 cement plaster (cement: fine sand) on rough face of brick walls

APPENDIX 2 Computation of building cost for a building with 10,000m² plinth area

Serial no	Materials/Labour	Unit	Statistical relation	Quantity for 10000m² plinth area	Rate, Rs	Amount, Rs
1.	Cement	tonnes	$0.1925A + 18.52$	1943.52	500.00	971760.00
2.	Fine sand	m³	$0.08A + 105.5$	905.50	25.00	22637.50
3.	Coarse sand	m³	$0.2592A - 80.94$	2511.06	40.00	100442.40
4.	20-mm coarse aggregate	m³	$0.2728A - 48.50$	2679.50	70.00	187565.00
5.	40-mm coarse aggregate	m³	$0.1164A - 20.74$	1143.26	70.00	80028.20
6.	10-mm coarse aggregate,	m³	$0.0151A + 73.91$	224.91	60.00	13494.60
7.	25-mm brick ballast,	m³	$0.0426A - 38.37$	387.63	60.00	23257.80
8.	Timber for formwork	m³	$0.005A + 11.19$	61.19	1800.00	110142.00
9.	Timber for joinery	m³	$0.0024A - 0.53$	23.47	2500.00	58675.00
10.	Ballies	m	$0.5507A + 797.5$	6304.50	8.00	50436.00
11.	Bricks	'00	$1.1829A - 524.23$	11304.77	250.00	282619.25
12.	Deformed bars	tonnes	$0.0479A$	479.00	4500.00	2155500.00
13.	Door shutters	m²	$0.0636A - 17.07$	618.93	170.00	105218.10
14.	Window shutters	m²	$0.1117A + 93.26$	1210.26	200.00	242052.00
15.	Glass	m²	$0.1407A + 55.99$	1462.99	40.00	58519.60
16.	Primer	lit	$0.0256A + 9.7$	265.70	15.00	3985.50
17.	Paint	lit	$0.0322A + 7.24$	329.24	22.00	7243.28
18.	Lime	quintals	$0.0754A - 51.21$	702.79	70.00	49195.30
19.	Surkhi	m³	$0.0204A - 18.39$	185.61	40.00	7424.40
20.	Marble chips	quintals	$0.1338A - 48.52$	1289.48	30.00	38684.40
21.	Marble powder	m³	$0.0012A - 0.36$	11.64	350.00	4074.00
22.	Mason	working days	$1.1314A - 407.4$	10907	16.00	174512.00
23.	Carpenter	working days	$0.7094A + 449.09$	7543	16.00	120688.00

Serial no	Materials/Labour	Unit	Statistical relation	Quantity for 10000m² plinth area	Rate, Rs	Amount, Rs
24.	Glazier	working days	$0.0122A + 10.31$	132	14.00	1848.00
25.	Painter	working days	$0.0905A + 37.26$	942	14.00	13188.00
26.	Blacksmith	working days	$0.479\ A$	4790	14.00	67060.00
27.	Bledar	working days	$6.055\ A - 2024.37$	58525.60	8.00	468204.80
	Basis fittings for doors assuming the size of door shutter as 2m × 1m, area of shutter=2m², total shutter area for the whole building=618.93m² no of doors $= \frac{618.93}{2} = 309.47$, say 310					
28.	100-mm hinges	nos	3 × 310 (3 hinges per shutter)	930	1.50	1395.00
29.	Mortice lock	nos	1 × 310 (one lock per shutter)	310	50.00	15500.00
30.	250-mm tower bolt	nos	1 × 310 (one bolt per shutter)	310	3.00	930.00
31.	Rainwater pipe	nos				
	100-mm diameter for total plinth area = 10,000m²; no. of storeys = 5; roof area $= \frac{10000}{5} = 2000$m²; therefore no. of rainwater pipes $= \frac{2000}{40} = 50$ nos (assuming one pipe serves 40m² of roof area) storey height = 3.1m length of each pipe= 3.1 x 5 = 15.5 + 0.5 = 16m approx. total length of pipe= 50 x 16 = 800m					
32.	100-mm diameter asbestos cement shoe	nos		800.0	15.00	12000.00
33.	100-mm diameter asbestos cement head	nos		50	6.00	300.00
34.	100-mm diameter asbestos cement bend	nos		50	6.00	300.00
				50	6.00	300.00
					total =	5449180.00
					add 0.25 percent for scaffolding =	13622.95
						5462802.95
					add 2 percent for water charges and sundries =	109256.05
						5572059.00
					add 10 percent contractor's profit and overheads =	557205.90
					total =	6129264.90
					total cost of building =	6129265.00
					plinth area rate =	613.00/m²

APPENDIX 3 Computation of building cost index for the year 1980 with respect to 1977 as the base year

Serial no.	Materials/Labour	Quantity	Unit	Year 1977 rate, Rs	Year 1977 amount, Rs	Year 1980 rate, Rs	Year 1980 amount, Rs
1.	Cement	1943.52	tonnes	365.00	709384.80	500.00	971760.00
2.	Sand	3416.56	m³	28.00	95663.68	32.00	109329.92
3.	Coarse aggregate	4047.67	m³	41.00	165954.47	70.00	283336.90
4.	Timber	84.66	m³	2000.00	169320.00	2100.00	177786.00
5.	Bricks	11304.77	'00	175.00	197833.47	250.00	282619.25
6.	Steel	479.00	tonnes	2200.00	1053800.00	4500.00	2155500.00
7.	Flush door shutter	618.93	m²	115.00	71176.95	170.00	105218.10
8.	Steel window	1210.26	m²	90.00	108923.40	200.00	242052.02
9.	Mason	10907.	days	13.00	141791.00	16.00	174512.00
10.	Carpenter	7543	days	13.00	98059.00	16.00	120688.00
11.	Blacksmith	4790	days	13.00	62270.00	14.00	67060.00
12.	Beldar	58525.6	days	6.75	395047.80	8.00	468204.80
			total		3269223.50		5158066.90

Notes: (*i*) quantities have been computed for a building with 10,000m² plinth area

(*ii*) cost index $= \frac{5158066.90}{3269223.50} \times 100 = 157.78$, say 158.

(*iii*) computation has been based only on major materials and labour