ENGINEERING PRODUCTION FUNCTION
AND
CHOICE OF TECHNIQUES
FOR BUILDING AND ROAD CONSTRUCTION

N. S. S. NARAYANA

INDIAN STATISTICAL INSTITUTE
NEW DELHI
1976

ACKNOWLEDGEMENTS

First and foremost I would like to thank Professor Kirit S.Parikh for the invaluable suggestions and criticisms he offered in his capacity as my research-supervisor. I owe a great deal for the encouragement and inspiration I received from him throughout my research. It has always been a great pleasure to work under his guidance. My gratitude to him is indescribable.

I am grateful to Professor T.N.Srinivasan who was kind enough to spare some of his valuable time in offering constructive criticisms at various stages of the preparation of this thesis. I highly benefited from several discussions with him on the subject matter of this thesis. I thank Professor B.S.Minhas for the interest he took in this project work and also for providing me excellent research facilities in the Indian Statistical Institute (I.S.I.), New Delhi. I thank Professor Pranab K.Bardhan for the comments he made after going through an earlier draft of this thesis. Thanks go to a host of others also among the staff of the I.S.I. who were very helpful in various discussions.

The staff of the libraries of the I.S.I. and the Planning Commission were very helpful in extending good library facilities. The staff of the Computer Centre of the Planning Commission also were very helpful. My sincere thanks to them.

I thank my colleagues Roopa and Asha for their help in reading the proof. Suresh Rao, Krishna and Shyamsunder also helped me at various stages of the thesis. Mehar Lal and B.L.Kumar typed the thesis fast and efficiently. I acknowledge

their cooperation.

Finally, I am very grateful to Annapurna who bore my stay away from her at New Delhi patiently and with alot of understanding.

Indian Statistical Institute N.S.S.

CONTENTS

Part I : Building Construction

Part II : Road Construction

Chapter I

1.1 INTRODUCTION

1.1.1 The Problem and the Scope of the Study

This study deals with the selection of technological alternatives of production, a problem referred to as "choice of techniques" in economic theory. Selection of an appropriate technique (or a technological alternative) has to be made with respect to specified objectives and available resources. Selection of proper techniques from among many available alternatives has been one of the main tasks while planning for economic development. Generally developing countries like India are handicapped by problems of scarcity of non-labour resources, abundant labour force, limited foreign-aid, limited technical know-how etc. to mention but a few of them. Hence detailed exercises on choice of techniques, separately for each sector of a given economy taking all the related constraints and objectives into account, are of great significance for proper planning. The subject matter of this project work is one such exercise. The **technical** alternatives are identified through engineering analysis and the choice of techniques is made in the context of the objectives of economic planning. In particular, the implications of the distribution of generated income in the selection of appropriate techniques are investigated.

This study is confined to the construction-sector of the Indian economy. Construction includes buildings, road and bridges, dams, irrigation works, industrial plants etc. This study however, covers only buildings and road construction.

The two exercises (for buildings and roads) proceeded in the following way: First the output is fixed as explained later in this chapter. Next, all the possible technical alternatives of producing this output are identified. Then all the technical and economic constraints, if any, are formulated. Optimal levels of the technical alternatives with respect to the specified objective (cost minimization or employment maximization) are then obtained by means of a linear programming model.

Various approaches have been adopted previously in dealing with the problems of choice of techniques. Generally statistical data, cross section or time series collected at the firm or plant level have been used in these approaches to identify various available alternative techniques. The results based on such ex-post data may not reveal the full potential flexibility and scope for choice of techniques. Analysis based on these data gets confined only to the range of statistical observations which may be quite narrow. In addition, these approaches generally identify only two factors, capital and labour, and treat them as homogeneous goods. Two points are to be noted here:

(a) Only capital and labour are considered as variables and current inputs are not; this may be alright if the output is narrowly defined in which case, not much change in the levels of current inputs is expected between techniques. However, if output is defined by the functional needs that they satisfy, the changes in current inputs may become significant and should be considered while selecting techniques.

(b) Capital and labour are in fact heterogenous. When capital is taken to be homogeneous it is assumed to be shiftable between techniques, which may not be important in choice of technique in a static framework. However the assumption of homogenity of labour and capital ignores the different skills of labour and types of capital required for different techniques and the various constraints on the availability of such skills and machines in the economy. Besides, it is necessary to identify labour of different income-classes separately for a simultaneous analysis of choice of techniques in the context of income distribution in the society.

The choice of technique from among several alternatives identified by econometric methods are in some studies based on the criterion of factor proportions or factor-productivity or rate of reinvestible surplus etc.

The implicit objectives behind these criteria are maximization of employment or achievement of full employment of the factors (in the case of factor-proportions), or maximization of output with the available limited stocks of factors (in the case of factor-productivity) or realisation of some desired future rate of growth of the economy (in the case of rate of surplus). The last criterion is motivated by the conflict between maximization of current output and future rates of growth. It is many times assumed that all reinvestible surplus would in fact be reinvested and that workers do not save anything. Both these assumptions may be questionable. In view of these shortcomings, we would like to break away from such conventional approaches at least on three accounts:

(a) In our analysis we will take all the relevant engineering considerations into account. An obvious advantage of this is the realization of the potential flexibility in the substitution possibilities among various inputs.

(b) Important current inputs, in addition to the factors, capital and labour, are explicitly accounted for. This provides a full scope for the optimal allocation of resources.

(c) Labour corresponding to different income-classes are identified. This gives an understanding of the distributional aspects of income in the society clearly and also facilitates the imposition of various constraints on the availability of certain skills of labour.

1.1.2 The Concept of Output

Usually in such exercises, the output is specified in terms of technical specifications of the materials used which seems to be a rigid criterion. The arguments generally given are that when materials are changed the outputs are different goods and the techniques for producing one good cannot be compared with the ones producing a different good. It need not be so, and some flexibility can be brought into our approach. If two outputs are substitutable having the same functional utility, the techniques in producing them can be compared, though these two outputs differ in technical specifications. For example, a stone-built house may be different from a brick-built house according to technical specifications. All the while, they correspond to the same type of output with a common functional utility: a house for living; and hence the techniques in producing them can be compared. Based on such an approach of functional utility, the output in the exercise on building construction is fixed to be 'a house'.

It is generally observed that the bulk of the single storey houses built in this country possess some common characteristics among themselves, apart from the architecture and 'finishes'. For example, the plinth area of these houses usually ranges from 300 to 500 square feet. The loads due to roof etc. are usually borne by the super-structure walls of these buildings. (An alternative way of constructing them is to build load-bearing reinforced cement-concrete columns at the corners of the building, and non-load bearing superstructure and partition walls).

The other common features of the single storey houses are that they generally have one sitting room, one bed room, one store-room, one kitchen and the usual facilities of bath and water closette. And in fact, these common features, forming the essential infrastructure of a building are the most important, from the point of view of functional utility of the house.

The architecture and "finishes" of these houses might vary from building to building. For instance, the walls of a building might not be plastered or even white-washed, whereas in some cases they might be plastered and painted with colours. Similarly the floor of a house might simply be a neat coat of cement or it can be even terrazo or mozaic flooring. Though such variations in finishings and architecture do exist from building to building, the essential infrastructure of single storey houses usually display negligible variation. Hence any analysis done on this part of the construction of a house can be easily applicable to most of the single storey houses. Moreover, the functional service, provided by this infrastructure of foundations, walls, floors and roofing is of strength and enclosure. The user can be considered to be indifferent to the technology of building this infrastructure. On the other hand people may have strong preferences regarding finishes such as colour and fixtures. Though one can normatively prescribe a set of finishes and examine the problem of choice of techniques of producing such finishes, the variations and combinations required would be very large. Hence this study is confined to the examination of appropriate techniques for the essential infrastructure of the house and the "finishes" are not included in the study. A representative single storey house serving as a modest dwelling is selected for this project work. It has a plinth area of 450 square feet(approx). It has one entrance-room, one sitting-room, one bed-room one store-room, one kitchen-cum-dining-room and a bath and water closette of specified dimensions. It is supposed to be a structure with load bearing walls. Any house with these characteristics is assumed to provide the same level of utility. Conclusions drawn regarding the construction of this house can be extended to single storey houses in general. Single storey house-construction is the major part of the building construction in India. Hence, this study can help us draw important conclusions on building construction in India. So the "output" in this exercise is the infrastructure essential from the construction point of view, of a single storey house.

In economic theory an isoquant is defined to be the locus of all efficient input-combinations for producing a given level of output. An input-combination is efficient if level of no input can be cut down unless level of at least one of the other inputs is increased . Different points on an isoquant indicate different input-ratios and also techniques of production for producing a specified level of output. These isoquants should be convex towards the origin and negatively sloped implying that for reducing the levels of some inputs, levels of some other inputs (at least one of them) have to be increased. However, if more than two inputs are considered, these isoquants might appear to be positively sloped, though still convex, in a two-dimensional frame (i.e. any one input versus a weighted sum of all the other inputs). Besides, with the definition of output based on functional utility, for a movement along an isoquant, not only the input-ratios change, but also the technical specification of the house may change (e.g. from a brick-built house to a precast-block-built house). Thus any "isoquant" drawn in this project on building construction is preferred to be called as an "isohouse" to distinguish its character from that of the usual isoquants commonly used in economic literature. An "isohouse" is defined to be the locus of all input combinations for producing a house providing a given level of functional utility.

The output of road construction is also similarly defined. Again the concept of functional utility is followed and the output in the exercise on road construction is fixed to be a "a road of one kilometre length with strength and traffic carrying capacity of a National Highway". This road can be an asphalt road or a cement concrete road or puzzolana concrete road etc. Techniques employed in building these roads will be compared, because the functional utility of these roads is the same viz., service as provided by a National Highway bearing a given traffic-density per day. An isoquant drawn in this analysis on road-construction will be called as an 'isoroad" for the same reasons for which we defined the notion of an isohouse.

1.1.3 Outline of the Analysis

Our first task is to identify all the technical alternatives (or techniques) in constructing a house or a road. Construction of a house is split into several stages. Various alternative ways of completing each of these stages are separately identified. Table 1. 1(a) below explains the basis of listing out these alternatives. A detailed list of all these alternatives is included in Chapter V. Common building techniques are all included in the model. For example, at the superstructure level, the choice-set i.e. list of the alternatives from which choice can be made consists of brick, stone (random, [illegible] and coarse stone) and precast block masonry techniques in different mortars of varying proportions. Similarly at the roof level, re-inforced cement concrete roofs of different concretes of different enegineering designs (see appedix A) are considered.

Table 1.1(a)

Guidelines for Preparation of Option-list of Technical Alternatives

(Building Construction)*

Stage	Method of Construction
(1) Foundation bed: (a) for load bearing walls (b) for partition walls	(i) lean concrete (ii) moderately strong concrete (iii) strong concrete
(2) Foundation of super-structure of load bearing walls	(i) brick in cement mortar (ii) brick in cement-lime mortar (iii) brick in lime-surkhi mortar (iv) stone in cement mortar (v) stone in cement-lime mortar (vi) stone in lime-surkhi mortar (vii) precast block in cement-lime mortar.
(3) Foundation and super-structure of partition walls	(i) brick in cement mortar (ii) brick in cement-lime mortar (iii) brick in lime-surkhi mortar (iv) precast block in cement-lime mortar.
(4) Roof	(i) 'Balanced'** roof in lean concrete, moderately strong concrete, strong concrete, (ii) over reinforced roof in cement concrete (iii) under-reinforced roof in cement concrete (iv) reinforced brick roof.
(5) Flooring	(i) brick flooring (ii) rough chiselled sandstone flooring (iii) finely dressed sandstone flooring.
(6) External plastering	(i) cement mortar plastering (ii) cement lime mortar plastering
(7) Internal plastering	(i) cement-lime mortar plastering (ii) cement mortar plastering (iii) lime-surkhi mortar plastering.

---

* See chapter V.

** For the meaning of these engineering terms, see footnote on page 119 of chapter V.

Similarly the construction of a road of given length is split into several stages. Various alternative techniques of production for each of these stages are enumerated. Tavle 1.1(b) presents the basis of listing out these alternatives. All the techniques that are commonly employed in the construction of National Highways are included in the model. It may be noted that in constructing roads for the performance requirement of National Highways, technological alternatives are very few.

Table 1.1(b)

Guidelines for Preparation of Option-list of Technical Alternatives (Road Construction)*

(1) Bituminous (Asphalt) Road**

(2) Cement concrete road with cement-concrete subbase

(3) Cement concrete road with water-bound macadem subbase

(4) Cement concrete road with lime-concrete subbase

(5) Puzzolana concrete road with lime-concrete subbase.

---

* See chapter V. ** Bitumen and asphalt are referred synonymously in this project.

Having listed out all the technical alternatives, the next task would be to determine the efficient combinations and appropriate levels of these alternatives for producing the house or the road as defined above. For this purpose a linear programming activity-analysis model is set up. The objective is to minimize the total cost of construction. The cost of operating an activity consists of the following:

cost of intermediate inputs (cement, steel,
bricks, lime etc.),

cost of direct-labour,

cost of transport (incurred in carrying the
materials to the site of
construction), and

miscellaneous costs, if any.

Now each intermediate input has to be produced first, before being available for construction. The costs on each intermediate input can also be accounted in a similar manner.

The need for breaking the cost of each intermediate input into several components arises due to the following reasons:

(i) The flexibility involved in defining the output based on its functional utility causes variation in the intermediate inputs from technique to technique. This leads to variation in the material resources also, other than capital and labour. Then such conversion of intermediate inputs into primary resouces allows exploring the subsititution possibilities between these resources also.

(ii) Construction is just one of the sectors of the Indian economy. The conversion of intermediate inputs into primary resources i.e. the explicit recognition of the activities of production of intermediate inputs provides a linkage to the other sectors of the economy. Then the shadow-prices of these primary resources given by a "master-programme" based on general equilibrium analysis involving all the sectors of the economy can be easily used in the "sub-programme" of the construction sector.

Hence, the costs of intermediate inputs are broken into

Costs of primary resources (including capital)
Costs of labour
and miscellaneous costs if any, required in the production of the intermediate inputs required in the construction of a building and a road. Prices used were those prevailing in 1972. Sum total of all the above mentioned costs (direct and indirect) total cost of construction. This cost minimisation is done subject to balance equations for resources, employment constraints corresponding to different wage-groups, output constraints, technical constraints. An initial solution is obtained by maintaining simply that the required output should be produced with a non-negative level of employment.

After the base solution is obtained, a thorough sensitivity analysis is conducted for the exercises both on buildings and roads. These are based on the (parametric) variation of the interest rate on capital equipment, levels of the employment both total and of the most unskilled labour, price of cement and bitumen per unit. In the case of road-construction these exercises include also the variation of the nature of the soil and life of the concrete-roads.

For both the projects (on buildings and roads) in the end we take up the variation of the objective function itself. Here, the total employment is maximised subject to a cost constraint, instead of minimising the total cost subject to a constraint on total employment. The need and methodology of all the above variations are explained later.

SECTION II

1.2 CONSTRUCTION SECTOR IN THE INDIAN ECONOMY

1.2.1 Why study the consruction sector?

The construction sector does not remain simply a sector to meet social need for housing but also acts as a prime-mover for Indan economic development. The level of construction activity provides a good index for the efforts the country is putting up for development.

Table (1.2) gives information for the years 1960-61 to 1972-73 about the capital formation in the form of construction and total gross fixed domestic capital formation in the country, at 1960-61 prices and also at current prices. Table (1.3) gives the same information in terms of percentages. Capital formation in construction is around 78 per cent more in 1972-73 than that in 1960-61. However, the increase in any year over the previous one is not steadily growing. Infact from 1966-67 to 1971-72 this growth rate is falling down. This is again reflected in table (1.4) which presents net domestic product at factor cost by construction sector. At 1960-61 prices, net domestic product from construction as a percentage of total net domestic product in the country has marginally

Table 1.2 : Domestic Capital Formation

(Rs. crores)

Item	1960 -61	1961 -62	1962 -63	1963 -64	1964 -65	1965 -66	1966 -67	1967 -68	1968 -69	1969 -70	1970 -71 *	1971 -72 *	1972 -73 *
Total Gross Fixed Domestic Capital Formation													
(i) current prices	2156	2410	2664	3149	3659	4132	4615	5224	5548	6083	6419	6978	7714
(ii) 1960-61 prices	2156	2315	2479	2801	3156	3333	3356	3629	3720	3887	3825	3939	4099
Construction													
(i) current prices	1337	1458	1548	1771	2036	2360	2768	3179	3401	3793	3985	4194	4569
(a) public sector	676	752	912	1144	1248	1377	1316	1246	1298	1499	1756	2095	2560
(b) private sector	661	706	636	627	788	983	1452	1933	2103	2294	2229	2099	2009
(ii) 1960-61 prices	1337	1386	1418	1588	1744	1881	2059	2236	2264	2343	2313	2294	2380
Machinery and Equipment													
(i) current prices	819	952	1116	1378	1623	1772	1847	2045	2147	2290	2434	2784	3145
(ii) 1960-61 prices	819	929	1061	1213	1412	1452	1297	1393	1456	1544	1512	1645	1719

* Provisional

Source: Tables 10 and 11 from National Accounts Statistics 1960-61 - 1972-73.

Table 1.3 : Gross Domestic Capital Formation by Types of Assets

(in Percentage)

year	gross domestic capital formation					
	at current prices			at 1960-61 prices		
	construction	machinery and equipment	change in stocks	construction	machinery and equipment	change in stocks
1960-61	51.8	31.7	16.5	51.8	31.7	16.5
1961-62	54.4	35.5	10.1	53.7	36.0	10.3
1962-63	50.7	36.6	12.7	49.6	37.1	13.3
1963-64	50.2	39.0	10.8	50.4	38.5	11.1
1964-65	50.0	39.9	10.1	49.9	40.4	9.7
1965-66	53.3	40.0	6.7	52.7	40.7	6.6
1966-67	51.5	34.4	14.1	53.0	33.4	13.6
1967-68	57.0	36.6	6.4	58.3	36.3	5.4
1968-69	58.2	36.7	5.1	57.9	37.2	4.9
1969-70	58.0	35.0	7.0	56.5	37.2	6.3
1970-71	55.6	33.9	10.5	54.5	35.6	9.9
1971-72	56.9	37.8	5.3	55.3	39.7	5.0
1972-73	56.7	39.0	4.3	55.7	40.3	4.0

Source: Statement V "Gross Domestic Capital Formation by types of assets" in National Accounts Statistics 1960-61 to 1972-73 published by C.S.O.

Table 1.4. : Net Domestic Product at Factor Cost by Industry of Origin

Industry	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71 *	1971-72 *	1972-73 *
Construction													
A. Current Prices													
(i) Rs. crores	625	651	683	782	923	1060	1248	1462	1564	1761	1901	2009	2141
(ii) Percentage of NDP	4.7	4.6	4.6	4.6	4.6	5.1	5.2	5.2	5.4	5.5	5.5	5.4	5.4
B. 1960-61 Prices													
(i) Rs. crores	625	645	668	752	809	865	939	1009	1032	1076	1068	1071	1102
(ii) Percentage of NDP	4.7	4.6	4.7	5.1	5.0	5.7	6.1	6.0	6.0	5.9	5.5	5.5	5.7
Total Net Domestic Product at Factor Cost													
A. Current Prices													
(i) Rs. Crores	13335	14085	14903	17089	20148	20801	24048	28430	29120	32240	34909	36879	39899
(ii) Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100
B. 1960-61 Prices													
(i) Rs. crores	13335	13825	14103	14882	16028	15234	15409	16802	17357	18338	19219	19479	19322
(ii) Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100

* Provisional

Source: Tables 3, 3.1, 4 and 4.1 from National Accounts Statistics 1960-61 - 1972-73 published by C.S.O.

increased from 4.7 percent to 6.1 percent from 1960-61 to 1966-67, while it fell down from 6.1 percent to 5.5 percent from 1966-67 to 1971-72. However the level of capital formation in the form of construction sector is generally so high that in any year since 1960-61, it accounts for more than 50 percent of the total gross domestic capital formation in the country as such.

Table (1.5) provides the information about the share of construction in the total fixed investment (gross) at several periods of time. For the fourth 5-year plan it was estimated that out of the total plan investment of around Rs.25000 crores, around 50 percent of it (i.e. Rs. 12000 crores) accounts for all types of construction works[1]. Out of this, building construction accounts for Rs.6000 crores of which housing alone takes Rs.3000 crores. For the fifth 5-year plan[1], of the total expected outlay of around Rs.50000 crores, the expenditure on contruction is expected to be not less than Rs25000 crores and according to the indications available, housing construction activity is expected to be stressed more in the future.

The importance of building construction can be further understood by looking at table 1.6.1.7 and 1.8[2]. These tables describe gross capital formation in construction by kind of services in absolute and percentage terms at current and 1960-61 prices. Since 1950-51 to 1970-71, barring two or three years building construction accounted for more than one fourth of the total capital formation in the form of construction. Infact, since 1966, it is more than one-third of the total. Both transport (which includes roads and bridges) and building

---

1. Report on Building construction: (1971).
2. Differences in the figures for total capital formation in construction given in table (1.2) and (1.6) and (1.8) are due to difference in sources of the data. However these differences are marginal.

Table 1.5 : Investment and Employment in Construction

	Real GNP (in billion Rs.) +	Real gross fixed investment as percent of real GNP +	Percent of real gross fixed Investment in construction +	Total employment (in millions) ***	Percent of total employment in construction	Percent of real GNP from construction
1950-51	100.1*	12.3	68.9	-	-	3.9
1955-56	117.4*	15.6	70.3	10.9	6.2	3.9
1960-61	139.4* 140.4**	14.8	63.8	12.1	7.0	4.5
1965-66	160.5**	20.1	54.6	15.5	6.5	4.9

\+ Source: (i) Estimates of capital formation in India: 1948-49 to 1960-61.

(ii) Estimates of capital formation in India: 1960-61 to 1965-66. C.S.O. (Govt. of India).

* at 1958-59 prices. ** at 1960-61 prices. *** excludes agricultural workers who numbered 31.5 millions in 1961.

Source: "Impact of Construction on Employment" by N.V.A. Narasimham in Employment and Unemployment Problems of The Near East and South Asia. Vol.II (ed) by R.G.Ridker and H.Lubell.

Table 1.6 : Gross Capital Formation in Construction by kind of Services: 1950-51 to 1970-71

(at current prices)

(Rs. crores)

Year	Dwellings[5]	Agriculture[1]			Transport[2]			Electricity	Manufacturing[3]	Others[4]	Total
		Non Resid.	Others	Total	Roads bridges	Others[6]	Total				
1950-51	231	18	194	212	25	36	61	21	33	42	600
1951-52	182	18	211	219	28	36	64	22	21	41	549
1952-53	145	19	152	171	34	35	69	35	77	48	545
1953-54	145	20	206	226	41	55	76	31	27	59	564
1954-55	195	20	154	174	50	46	96	34	85	62	646
1955-56	194	21	176	197	74	59	133	52	87	103	766
1956-57	314	23	182	205	72	77	149	59	109	130	966
1957-58	210	24	192	216	76	126	202	74	99	101	902
1958-59	220	26	248	274	76	162	238	51	85	113	981
1959-60	314	27	229	256	84	141	225	93	45	149	1082
1960-61	377	30	291	321	123	165	288	54	121	185	1346
1961-62	407	32	320	352	135	166	301	109	102	194	1465
1962-63	367	33	330	363	150	214	364	130	119	210	1553
1963-64	319	34	362	396	182	255	437	203	206	210	1771
1964-65	402	37	455	492	187	274	461	200	231	256	2042
1965-66	551	37	488	525	171	260	431	302	212	338	2359
1966-67	931	40	525	565	181	210	391	252	178	416	2733
1967-68	1239	46	619	665	177	179	356	255	146	494	3155
1968-69	1240	49	689	738	179	186	365	292	181	493	3309
1969-70	1369	56	458	714	191	182	373	329	388	537	3710
1970-71	1457	62	791	853	218	207	425	393	222	565	3915

---

1. Agriculture includes livestock, forestry, hunting, lagging and fishing.
2. Includes communication also.
3. Includes mining, quarrying, construction in registered and nonregistered factory sector.
4. Others includes all economic and noneconomic services other than those indicated in columns 2 to 10.
5. Relates to urban and rural households only 6. Includes railways, posts and telegraph and others

Source: R. N. Lal in Economic Times, Feb. 19, 1975.

Table 17 : Gross Capital Formation in Construction by kind of Services:
1950-51 to 1970-71
(in percentage at current prices)

Year	Dwellings	Agricultural	Transport	Electricity	Manufacturing	Others	Total
1950-51	38	37	10	3	5	7	100
1951-52	33	40	11	4	4	8	100
1952-53	27	31	13	6	14	9	100
1953-54	26	40	13	6	5	10	100
1954-55	30	27	15	5	14	9	100
1955-56	25	26	17	7	11	14	100
1956-57	33	21	15	6	11	14	100
1957-58	23	24	23	8	11	11	100
1958-59	22	28	24	5	9	12	100
1959-60	29	24	21	8	4	14	100
1960-61	28	24	21	4	9	14	100
1961-62	28	24	21	7	7	13	100
1962-63	24	23	23	8	8	14	100
1963-64	18	22	25	11	12	12	100
1964-65	20	24	23	10	11	12	100
1965-66	23	22	18	13	9	15	100
1966-67	34	21	14	9	7	15	100
1967-68	39	21	11	8	5	16	100
1968-69	37	22	11	9	6	15	100
1969-70	37	19	10	9	10	15	100
1970-71	37	22	11	10	6	14	100

Source : "Capital Formation in India". by R.N.Lal in Economic Times Feb. 19, 1975.

Table 1.8 : Gross Capital Formation in Construction by kind of services: 1950-51 to 1970-71

(at 1960-61 prices)

(Rs. crores)

Year	Dwellings	Agriculture	Transport and communications	Electricity	Mining Manuftng. and Construction	Others	Total
1950-51	305	269	82	28	44	57	785
1951-52	231	265	82	28	28	55	689
1952-53	182	205	88	44	98	61	678
1953-54	201	276	97	30	34	71	718
1954-55	248	217	123	43	109	80	820
1955-56	242	237	170	66	111	135	961
1956-57	327	239	174	66	127	156	1137
1957-58	237	236	221	81	108	185	998
1958-59	241	298	253	53	91	182	1045
1959-60	332	264	234	97	47	190	1130
1960-61	377	321	288	54	121	136	1346
1961-62	386	337	286	104	97	182	1392
1962-63	333	342	331	118	108	190	1422
1963-64	286	364	390	181	182	186	1589
1964-65	348	411	397	173	199	221	1749
1965-66	447	401	345	242	171	275	1881
1966-67	702	406	237	191	135	318	2034
1967-68	884	429	255	186	108	357	2219
1968-69	834	453	249	201	126	340	2203
1969-70	850	406	237	209	246	344	2292
1970-71	856	445	255	236	139	342	2273

Source: "Capital Formation in India" by R.N.Lal in Economic Times, Feb. 19, 1975.

construction together account for nearly one-half ofthe total capital formation in the form of construction. However, the level of house construction activity in India seems to be much below what might be considered the desired level from normative considerations . We examine in the next section the present availability and need for housing in the country. The level of construction activity will have to size substantially on the future making it even more useful to study the choice of techniques in this sector, particularly since the sector has a large potential for employing unskilled labour.

1.2.2 Availability of and Need for Housing

Housing is a necessity and is next to food and clothing in importance. India is suffering from chronic shortage of housing. Widely varying estimates were put up regarding the housing shortage in India. Mathur[1] estimates the acute shortage of houses to be of the order of 84 million units. Another estimate[2] of current shortage according to National Buildings Organisation is of the order of 21 million units of which 18 million correspond to rural areas and 3 million correspond to towns and cities. In rural areas, where 80 per cent of of our population lives (see page 27) the condition of 70 million houses is considered so bad that they are required to be rebuilt or thoroughly repaired[3].

---

1. G.C. Mathur: (1972).
2. Times of India (26 April, 1974).
3. G.C.Mathur (1973).

It is obvious that any of these estimates cannot be blindly believed especially when they so widely differ. Differences in these estimates may be due to differences in (a) definition of the housing unit, (b) estimation procedure and (c) the time periods considered none of which is clearly specified. Hence we make our own estimate in clearly defined terms.

Tables 1.9 and 1.10[*] present the percentage distribution of households by number of rooms and households, for rural and urban households respectively, a sample survey carried out by NSS. As the samples are fairly large sized and are spread all over India, the information contained in these tables may be generalized for all Indian households. We would like to estimate the housing shortage (defined as the additional dwelling accommodation required for meeting the minimum necessary level) in India by means of a value system (given below) devised by ourselves:

(i) Two persons (or less) require minimum one room to live,

(ii) Three or four persons require minimum two rooms to live,

(iii) Five, six or seven persons require minimum three rooms to live,

(iv) Eight or nine persons require minimum four rooms to live,

(v) Ten (and more) persons require minimum five rooms to live.

---

[*] These tables are based on the National Sample Survey, 19th round, July 1964 - June 1965 No.195: Tables with notes on housing condition.

Table 1.9 : Percentage Distribution of Households by Number of Rooms and by Household size All India : Rural

No. of Sample households : 15041. No.of Sample Villages: 8472 (a) base: all households

No. of rooms	Household size												
	one	two	three	four	five	six	seven	eight	nine	ten and above	not recor-ded	all	No. of sample households
one	4.70	5.82	6.57 (1)	6.63 (1)	6.00 (2)	4.73 (2)	2.95 (2)	1.67 (3)	0.75 (3)	0.64 (4)	0.01	40.47	6188
two	1.28	2.72	3.98	5.23	5.80 (1)	4.59 (1)	3.90 (1)	2.10 (2)	1.15 (2)	1.45 (3)	0.02	32.52	2448
three	0.30	0.78	1.19	1.82	2.11	1.91	1.77	1.28 (1)	0.83 (1)	1.48 (2)	0.01	13.48	2036
four	0.16	0.26	0.42	0.64	1.24	1.13	0.94	0.63	0.56	1.09 (1)	-	7.27	1057
five	0.06	0.06	0.14	0.28	0.32	0.37	0.39	0.35	0.22	0.66	-	2.85	410
six	0.02	0.04	0.05	0.07	0.17	0.15	0.23	0.12	0.18	0.46	-	1.63	109
seven and above	0.03	0.08	0.05	0.14	0.13	0.25	0.12	0.14	0.16	0.54	-	1.64	227
Not recorded	0.11	0.07	0.08	0.05	0.07	0.08	0.05	0.03	0.03	0.04	-	0.61	103
Total	6.66	9.83	12.48	14.86	15.84	13.21	10.13	6.66	4.00	6.30	0.03	100.00	15041
No.of sample households	964	1434	1809	2237	2382	2032	1557	1038	611	972	5	15041	

Sourc: The N.S.S. 19th round July 1964 - June 1965. No. 195.

Note: Figures in the brackets are added by the author.

Table 1.10 : Percentage Distribution of Households by Number of Rooms and Household size : All India : Urban

No.of sample blocks : 4572. No. of sample households :9951. (a) base : all households

No.of rooms	Household size												
	one	two	three	four	five	six	seven	eight	nine	ten and above	not recor-ded	all	No.of sample households
One	14.52	6.47	6.38 (1)	7.11 (1)	5.96 (2)	4.64 (2)	2.93 (2)	1.78 (3)	0.97 (3)	1.12 (4)	0.06	51.94	5072
two	1.07	1.97	2.56	4.56	3.92 (1)	3.74 (1)	3.47 (1)	2.22 (2)	1.34 (2)	1.45 (3)	0.01	27.21	2678
three	0.50	0.52	0.78	1.17	1.60	1.52	1.29	0.97 (1)	0.80 (1)	1.18 (2)	0.0	10.33	1068
four	0.19	0.15	0.33	0.44	0.72	0.52	0.77	0.45	0.40	0.69 (1)	-	4.66	501
five	0.07	0.10	0.08	0.14	0.16	0.29	0.24	0.29	0.24	0.50	0.04	2.15	223
six	0.11	0.05	0.08	0.04	0.09	0.25	0.14	0.17	0.10	0.27	-	1.30	141
seven and above	0.04	0.01	0.07	0.13	0.13	0.08	0.13	0.14	0.09	0.46	-	1.28	138
Not recorded	0.99	0.05	0.05	-	-	-	0.03	0.01	-	-	-	1.13	130
Total	18.39	9.32	10.33	13.59	12.58	11.[illegible]4	9.00	6.03	3.94	5.67	0.11	100.0	9951
No.of sample households	1948	904	991	1305	1213	1110	891	605	378	594	12	9951	

Source: The N.S.S. 19th Round July 1964 - June 1965. No. 195.

Note: Figures in the brackets are added by the author.

Based on the above value system, the households facing housing shortage in terms of having too few rooms were identified from tables 1.9 and 1.10. The boxed portions of these tables represent shortage zones. Figures in brackets there indicate the shortage of rooms, by each respective household size.

According to 1970 census houselist, there were about 97 million households in India (77.9 million in rural and 19.1 million in urban areas)[1]. Using this information along with tables 1.9 and 1.10, additional rooms required to wipe out the current shortage, are estimated and given in table 1.11, and summarized below:

No. of additional rooms required per unit	Units requiring Additional Rooms Rural	 Urban
1	33.93 million	5.17 million
2	14.35 million	3.50 million
3	3.01 million	0.81 million
4	0.50 million	0.21 million

The average household sizes as observed in the 1970 houselist are 5.61 in rural areas and 5.49 in urban areas.[2] According to the above value system this implies an average house (required by an average household)

---

[1] Registrar General and Census Commissioner, (1974)

[2] Registrar General and Census Commissioner, (1972).

Table 1.11: Estimates of the additional rooms required to wipe out the current dwelling shortage.

(in million)

Room-wise Requirement	Rural	Urban
One room requirements	77.9 x (0.0657 + 0.0663+0.0580 + 0.0459+0.0390 + 0.0128+0.0083 + 0.0109)=23.93	19.1 x (0.0638 + 0.0711+0.0392 + 0.0374+0.0347 + 0.0097+0.0080 + 0.0069)=5.17
Two room requirements	77.9 x(0.0600 + 0.0473+0.0295 + 0.0210+0.0115 + 0.0148)=14.35	19.1 x (0.0596 + 0.0464+0.0293 + 0.0222+0.0134 + 0.0118)= 3.50
Three room requirements	77.9 x (0.0167 + 0.0145+0.0075) = 3.01	19.1 x (0.0178 + 0.0097+0.0145) = 0.81
Four room requirements	77.9 x 0.0064 = 0.50	19.1 x 0.0112 = 0.21

should contain minimum three rooms, both in rural and urban areas. So, we define a 'standard' unit = 3-room house. Then the shortage in terms of the standard units will be as follows:

Rural shortage

23.93 million one-room houses imply 7.98 million standard units.

14.35 million two-room houses imply 9.57 million standard units and so on.

The total housing shortage in rural areas of India in 1970 thus comes to 21.23 million standard units.

Urban shortage

5.17 million one-room houses imply 1.72 million standard units, etc.

The total housing shortage in the urban areas of India, by 1970 comes to 5.13 million standard units.

Adding the shortages in the rural and urban areas our estimate of the housing-shortage in India comes to be 26.36 million standard units. (as on 1970) of three rooms each.

The annual rate of construction of dwelling units in India is around 1.15 million units[1] (definition of the unit is not given). That consists of 0.65 million units in rural areas and 0.5 million units in urban areas. By way of population growth, India is adding approximately

---

[1] Time of India (26 April 1974).

15 million heads (2.5%) every year. If we assume that one dwelling unit is required per every five persons, we would be requiring an annual rate of 3.0 million units of construction, merely to maintain the present level of shortage of housing. With growing population, the inadequacy of housing is bound to assume gigantic dimensions, unless compensating measures are taken.

The reasons for the above lag in the performance may be traced back upto the shortage of cement in India. Though construction, is an important sector of the Indian economy its level of operation has been crippled by the shortage of cement. Indigenous availability of cement has assumed to be such a special problem associated with the construction sector of the Indian economy that, finally a ban had to be imposed on construction of certain types. Before we discuss this special problem in a later section, let us review the employment implications also of this sector. Construction is an important source of employment of unskilled labour force. The ban imposed by the government of India a few years ago is supposed to affect the employment of an estimated figure of 66 lakhs or so.

1.2.3 Employment Potential of the Construction-Sector

India has 250 million adult workers approximately. 16 million of them are in construction sector alone, forming 3 percent of the population[1]. 66 million of them a

---

[1] The Times of India (24 December 1974).

are supposed to be engaged in building works. This information is corroborated by table (1.5) which says, around 7 percent of the total employment (excluding agricultural workers) is provided by construction industry itself. Of this 7 percent, roughly 50 percent is absorbed in building construction alone. Transport and Communication approximately provide 17 percent of the total employment in construction (see table 1.12).

By nature, construction industry is labour-intensive providing employment to both, skilled and unskilled persons. It was found by the Institute of Applied Manpower Research Institute[1], New Delhi, in one of their analyses based on information collected in 1964, that out of the total number of 18608 graduate civil engineers in employment, about 9671 were engaged in only building construction and design. That means around 52 percent of the total graduate civil engineers are engaged in building construction. Besides, considering the linkage effects that this sector has, construction should play an important role in wiping out considerably a large part of the unemployment, of educated as well as uneducated persons in this country.

Hence, construction activity is likely to be maintained at a high level. The low level of construction activity in India may be ascribed primarily due to poverty of its people. Lack of sufficient financial resources can

---

1| G.C. Mathur (1973)

Table 1.12 : The distribution of construction workers in India : 1961

	No.(in '000)	Percentage
Buildings	469	49.7
Irrigation	309	32.8
Transport	140	14.8
Communications	25	2.7
	943	100.0

The percentage distribution of workers engaged in construction activity in India: 1961

Craftsmen and production process workers	83.9
Administrative and Executive workers	4.9
Clerical	4.6
Professional and Technical	2.6
Transport and communications	1.8
Services	1.3
Others	0.9
	100.0

Source: "Impact of Construction on Employment" by N.V.A.Narasimham in Employment and Unemployment Problems of the Near East and South Asia, Vol.II (ed.) by R.G.Ridker and H.Lubell.

be the reason for the low level of investment in the construction sector. This can be solved only through overall economic development of the country, which is a long-term process. However, the low level of construction activity is many times ascribed to certain short-term factors also; viz., non-availability of some resources like steel, cement, lime of prescribed quality, etc. In fact in India it is very frequently heard that shortage of cement is a serious problem hindering the construction activity. If it were true, it is necessary to search for alternative techniques which use commonly available resources like lime, surkhi etc. serving as substitutes to cement.

SECTION IV

1.2 A SPECIAL PROBLEM OF CONSTRUCTION SECTOR - THE SHORTAGE OF CEMENT

Cement shortage does not seem to be a recent phenomenon. 'In 1951-56, cement production was 4.6 million tons (m.t.) against a demand of 4.8 mt. Therafter the gap widened - 7.7 mt. against 8.8 mt. in 1956-57, 10.8 mt. against 13 mt. in 1961-62 and 15 mt. against 19 mt. last year, a shortage 4 mt.[1]

Lack of proper planning not only in cement production but also in other sectors having linkages with it, seems to be the only explanation for this shortage. Estimates Committee of Parliament[2] in its report observed that the

---

[1] Science To-day, (January 1975)

demand for cement has been underestimated since the Second plan. It noted that demand originating from unorganized industrial sector, housing in rural areas etc. has not been taken into account at all. Besides, power shortage, coal shortage, wagon shortage have their own impact on cement production. Cement production has slipped to 70 percent of the total installed capacity of 19.7 mt. last year compared to 80 to 88 percent a few years ago. Wagon shortage added artificial scarcity to natural one by not transporting the little amount produced to working sites.

Science Today[1] in a special study on cement notes the following: "The future appears even bleaker. At an annual growth rate of 8 percent, the Ministry of Industrial Development has estimated the demand for cement at 28 mt. in 1978-79. This would need a total capacity of 33 mt. to work at an assumed 85 percent efficiency. Though the capacity sanctioned for 1978-79 total 32.4 m.t., e bulk of this, about 9 mt., is due for completion only in 1977-78. The actual capacity in 1979, therefore, is likely to be only 23 mt.; and at 85 percent capacity utilization this could at best give only 20 mt. leaving a wider gap of 8 mt." This is an approximate situation. For exact production values of cement see Tables 1.13 and 1.14.

---

[1] Science Today (January 1975).

Table 1.13 : Regional Imbalance in Demand, Capacity and Cement Consumption in 1972

(in million tons)

	North	East	West	South	Total
Actual capacity	3.438	3.239	3.610	7.423	19.760
Actual Prodn..	2.723	2.491	4.461	6.038	15.713
Demand	4.723	3.025	4.433	4.562	16.743

Source: "Is the Cement Industry Well-Fed?" by M.S.Doraiswamy in Science Today, January 1975.

Table 1.14 : Targets of Capacity and Production and Achievement

	Target of capacity	Capacity installed	Target of Prodn.	Actual Prodn.
Base 1950-51	-	3.28	-	2.95
1st Plan 1951-56	5.31	5.02	4.80	4.60
2nd Plan 1956-61	16.00	9.30	13.00	7.97
3rd Plan 1961-66	15.00	12.00	13.00	10.82
Plan Holiday 1966-69	-	14.96	-	12.24
4th Plan 1969-74	21.20	-	19.00	-
1970-71	-	17.59	-	14.55
1971-72	-	19.55	-	15.20

Source: (Report of Task Force on Cement Industry) or "The Growth of the Cement Industry" in Monthly commentary on Indian Economic Conditions" by Indian Institute of Public Opinion Vol. XV, No. 2 (September 1973).

One can question the optimism involved even in that 20 mt. estimate. For instance, power shortage may not allow even 85 percent capacity utilization. Quality of limestone may not yield expected output. Producers may not take up production at the prices set by the Government.

However, we have had a fairly ambitious programme of exporting cement. Table 1.15 provides the information in terms of tonnes, on export of cement since 1951 by this country. It appears, however, that at present very little cement is being exported. The Ministry of Heavy Industry and Civil Supplies is keen to export 1.5 million tons of cement to oil producing countries in West Asia for financing the imports of furnance oil.[1]

Essentially two factors can play main role in wiping out the domestic shortage and exporting cement: provision of suitable infrastructure for the development of cement-industry, and designing a proper economic policy. The former includes creation of sufficient capacity, assurance of raw material supply (by the Government to producers) etc. and these things can be taken care of only in the long run. The latter involves mainly a price. control on cement sale. This is a short run measure. An increase in the price of cement per ton might reduce the demand for it. However, this implies that house-builders should look for alternative

---

1/ This information is based on a report in Indian Express January 12, 1975. Details regarding when and over what period this 1.5 million tons are to be exported not provided there.

Table 1.15 : Exports of Cement

('000 tonnes)

Year	Quantity	Year	Quantity
1950-51	29	1965-66	39
1955-56	57	1966-67	14
1960-61	92	1967-68	49
1961-62	98	1968-69	205
1962-63	35	1969-70	135
1963-64	81	1970-71	168
1964-65	31		

Source: Ministry of Foreign Trade.

or Table 57. Basic Statistics Relating to the Indian Economy, by Statistics and Survey Division, Planning Commission, New Delhi (1950-51 to 1970-71).

production techniques, which require less of or no cement at all and thus substituting other materials for cement in construction. The exercise on thevariation of cement price is intended for such an analysis.

Chapter II is devoted to reviewing the past literature on choice of techniques. In that chapter, while explaining the conventional approaches we note their shortcomings also. Need for engineering production function and its importance for the problem of choice of technology at a micro level is then discussed. In chapter III the works and studies that have already been done on the Indian construction sector are reviewed. The analytical model used in this study to identify the appropriate technology is described in chapter IV. Chapter V displays the data-base of this study. Chapter VI is split into two parts I and II. Part I presents the results obtained under building construction. Part II presents the results obtained under road construction.

Appendix containing all the engineering calculations of the building and road construction is given after Chapter VI. It is followed by all the data based on which this project-study is carried out.

Chapter II

REVIEW OF LITERATURE ON CHOICE OF TECHNIQUES

2.1 Importance of the problem of choice of techniques

In development planning, allocation of investment resources is a major problem. This involves several choices at different levels, viz. determining the levels of investment for different sectors of the economy, selecting different projects within a sector and choosing the proper techniques of production for a specified project. Hence choice of techniques is an integral part of the development policy of an economy. The number of alternative techniques might be very large and different techniques usually imply different strategies of development. Quite often conflicts arise between the implications of various criteria of selecting the techniques of production. The importance of a criterion emerges out of the various social objectives and resource constraints.

Capital and labour are two factors required for production of other commodities. A technique is usually defined by various factors such as capital and labour required for producing a given amount of output. Given a range of techniques, selection of an optimal techniques depends upon the objectives and constraints present in the system. The objective may be to maximize employment or to maximise social marginal productivity of investment (when capital is scarce) or to maximize profits or output, or to minimize cost of production and so on. The constraints can be resource constraints. Selection of optimal techniques involves, among others, the following considerations: (a) Is it an economic choice or an engineering choice? The distinction between these two will be taken up later in this chapter. (b) Is the choice to be made at the micro level or the macro level? An economy interested in maximizing overall employment need not necessarily employ labour intensive techniques in all of its projects. (c) Who makes the selection; public policy maker or a private enterpreneur? The objectives of these two might be different. There is no reason why a private enterpreneur would sacrifice his profit for the sake of the society. He might use a technique which gives him more profits, while the government might adopt the one that provides more present consumption, because such consumption accrues to the poor. Technically such conflicts do not disappear even in socialist countries; but they are not important there, because there is no private sector and so no private profits; and conflict, for example, can exist only to the extent that present and future consumption levels conflict. However, in the countries where both public and private sectors coexist, the government might be able to influence the private sector in adopting a particular technique-set in view of the benefits that can accrue to the society. This can be done by manipulating taxes and subsidies on factors of production. Whether producers react to such policies of government and how far such manipulations are effective in the real world, form altogether a different set of questions.

2.2 Does choice exist?

Thus the question of choice of techniques is important. And in the real world, infact alternatives do exist, and a selection has to be made. However, it may be that not all the sectors of an economy are technologically flexible. A number of recent empirical studies have suggested that there is infact not much scope for choice of techniques in quite many industries. R.B.**Sutcliffe's**[1] study in this connection is mentionable. To assess how wide is the spectrum of techniques for particular industries, he did a comparison of statistics measuring capital intensity within and between different countries and at different times. A part of his study consists of the ratios of the highest to lowest average capital intensity among four countries, the United States, Mexico, Columbia and India, in 1945/50 separately for different divisions within the manufacturing sector. Barring the differences in the composition of output within the major categories of production between different areas, on the face of it a high ratio would be some indication of

---

1/ R.B. Sutcliffe, (1971).

technological flexibility, as it appears that there is a wide range of techniques in use. Though his conclusions about technological flexibility are supposed to be exceptionally tentative, it is worthwhile to note what they are:

For the four countries taken together, grain-mill products, iron and steel and cotton yarn and cloth divisions of the manufacturing sector seem to be highly technologically flexible. Tobacco manufactures are also fairly flexible whereas printing and publishing is comparatively inflexible. However, one may note that the statistics based on ex-post data collected by Sutcliffe may not reveal as much the potential flexibility of a sector as ex-ante data based on engineering considerations might do (this particular point will be elaborated later in this chapter). Also his study lacks the investigation of the implicit objectives involved in the choices already made and the constraints under which such choices are made. India, or Mexico or Columbia might have imported the technology (due to tied foreign-aid, say) from a foreign country, may be from the United States itself. Then the observed capital-intensities might correspond to the domestic conditions of the foreign country rather than of the importing countries.

His observations on construction industry also are interesting. He concludes that construction activities have enormous range of possible techniques. " This is true of buildings, the construction of dams and other earth moving operations ...... When methods in construction are labour intensive, they tend to use large amounts of unskilled rather than technically skilled labour, though of course in consequence this demands considerable quantities of supervisory labour".

The flexibility of this sector should have been a boon, especially for developing and over populated countries. In chapter I we have already noted the importance of this sector in terms of the gross fixed capital-formation in India. All development programmes require construction. Technological flexibility of an industrial programme is different from that of its construction part. Hence, a proper selection of techniques in the construction sector can significantly increase the employment level in India.

2.3 Previous research

The vast amount of research done in this field of economic planning can be classified into those corresponding to problems of the macro-level or the micro-level. At the macro-level the problem deals with the criterion of investment in several sectors of the economy. These criteria include social marginal productivity (SMP) criterion suggested by A.E.Kahn and H.B.Chenery, marginal per capita reinvestment quotient (MRQ) criterion by

Galenson and Leibenstein, marginal growth contribution criterion by Eckstein and reinvestible surplus criterion by Dobb and Sen. For a criticism and an excellent review of these criteria, works by Srinivasan[1] and United Nations, ECAFE[2] may be referred. At the micro-level the problem deals with the choice of techniques of production within a project. As we are concerned, in this project, with the problem of choice of techniques of production at a micro-level, we would review only the research done for micro-level planning.

Past research, in the context of micro-level planning, can be broadly classified into the following three approaches:

(i) Observing factor-proportions or factor-productivities and rates of reinvestible surplus for different techniques and selecting the appropriate techniques subject to given factor endowments position or anticipated future growth pattern of the economy.

(ii) Slightly different way of going about is to fit econometric production function using cross-section or time-series ex-post data, and select a technique depending upon the relative price-structure of the factors of production in the economy.

(iii) An altogether different approach is to bring relevant engineering considerations into the picture. This can be done either by "analytical method' or

---

1/ T.N. Srinivasan (1962).

2/ United Nations, ECAFE (1961).

"experimental method" (to be explained later) or a mixture of these two. This approach is ex-ante in nature.

Following pages are devoted to noting the relative merits, conceptually as well as in applicability, of the above approaches. We will take up one by one.

2.3.1 Approach based on factor proportions, factor-productivity and rate of reinvestible surplus

A technique may be defined either in terms of factor-ratios viz. capital to labour or factor-output ratios, viz., capital to output or labour to output etc. If we define a technique by the amounts of capital and labour required to produce a unit of output (i.e. capital-output ratio and labour-output ratio), the problem of selection of a technique arises whenever efficient* alternative techniques consuming more(less) capital but less (more) labour are available to produce the same unit of output. In this case, maximization of output, while certain factors are scarce, dictates the selection of techniques of production. Alternatively, a technique may be defined in terms of the proportions of the factors used. In this case, relative scarcity of different factors of production dictates the selection of techniques so that scarce factors are used sparingly and vice versa.

According to the definition based on factor-output ratios, the term factor "intensity" of a technique is

---

* Inefficient alternative is the one using more of both the factors to produce the same level of output.

relative to other techniques, but not relative to other factors. According to the definition based on factor proportions factor "intensity" is relative to other factors. Under this latter definition a capital intensive technique is necessarily labour-saving. It should be noted that the two definitions of a "technique" may not lead to identical results, unless the inefficient techniques are eliminated. Let us write

$$\frac{K}{O} = \frac{K}{L} \times \frac{L}{O}$$

It is obvious that $\frac{K}{O}$ need not change with a change in L. In other words capital per unit of labour and labour productivity may change in such a fashion that they cannot affect the capital productivity. Hence a high capital-productivity can be consistent with low capital per unit of labour.

Future rate of growth depends on investment or saving (assuming absorptive capacity of capital) generated out of the surplus realized by adopting any particular technique. Hence not merely the factor proportions or factor productivity but the surplus realized also matters for selection of any technique. There are many studies adopting this approach for studying the problem of choice of techniques, especially in the Indian context. These include, among others, works by A.K.Sen[1] and K.N.Raj[2]

1/ A.K.Sen (1968).

2/ K.N.Raj (1956).

(separately) for textile industry, J.C.Sandesara[1] for Indian small scale and large scale industries, Chatterjee[2] etc. for mustard oil industry etc. A.S.Bhalla[3] for textile industry, etc.

Sen saw the problem in the following way: workers do not save anything, while capitalists do and reinvest the entire surplus. The wage rate is fixed. So adoption of labour-intensive (employment maximising) techniques will maximize current consumption whereas capital intensive (profit maximizing) techniques by diverting the distribution of income in favour of capitalists will produce maximum rate of growth of consumption. Sen worked out the case of Ambar Charka as a technique of cotton spinning. He calculated the productivity of labour, net surplus per unit of output and finally rate of surplus per unit of capital-investment from the actual data. He concluded that this programme is inflatory and is also likely to affect capital accumulation adversely.

However, Sen's assumptions have been questioned. He assumed that there is a limited stock of capital available to start with and all the surplus can be [illegible] reinvested by capitalists (absorptive capacity of capital). Such assumptions about availability and absorptive capacity

---

1/ J.C.Sandesara (1969).

2/ Chatterjee(1963)

3/ A.S.Bhalla (1964).

of capital in the economy are the direct contributors for the results he obtained. R.B.Sutcliffe[1] argues that ' "assumptions about the distribution of income, the taxation system, the nature of economic system, the inducement to invest and many other factors have absolutely crucial affects on the conclusions which can be drawn from theoretical discussions of the problem of choosing an appropriate industrial technology". Besides, if the society values the consumption by the poor more than that by the rich, then Sen's type of argument against labour-intensive techniques is not conlusive[2]. There may be valid reasons for such a differential valuation by the society. As Gunnar Myrdal points out, one of the factors contributing to this low level of productivity (of labour) in very poor countries is the low level of consumption of a major proportion of population resulting in extensive malnutrition. If we assume that higher consumption results in higher productivity (without a great time lag), then Myrdal's hypothesis would in fact justify the adoption of labour-intensive techniques. The lower savings and the lower stock of capital in future may more than be compensated by the increased productivity of labour. In addition, the problem of income distribution in the society is solved directly by generating the incomes to the lower strata of the population at the time of

---

1/ R.B.Sutcliffe, (1971).

2/ This statement is not applicable to Ambar Charka. Ambar Charka is shown to be a dominated technique.

production itself and thus creating higher purchasing power at their disposal. This may be important in countries where the political institutional system is unable to redistribute income after it is generated.

The truth regarding the low rate of surplus of labour intensive techniques still remains to be empirically verified. Very few attempts have been made so far in this direction. J.C.Sandesara's study[1] is concerned with the interrelations found among size, capital intensity and other economic characteristics in the Indian Industry. Average number of workers employed per day denotes the size, and capital-intensity is measured by the quantity of capital employed per worker. The economic characteristics concentrated upon are output, wages and surplus, each per worker, and also output and surplus, each per worker. It covered the 29 industries reported in the census of Indian Manufactures, and related to the period 1953-58. A brief summary of his tentative conclusions based on an extensive correlation analysis is the following:

(i) Small units of not all industries are labour-intensive.

(ii) Small units have lower output, lower wage and lower surplus, each per worker, and also lower output and lower surplus, each per unit of capital than larger units.

(iii) (a) Labour-intensive technique has higher output per unit of capital than capital intensive technique.

---

[1] J.C.Sandesara, (1969).

(b) "The hypothesis that labour-intensive technique has lower surplus per unit of capital than capital-intensive does not find support from any type of data. Actually, the evidence on the ten and six[1] industries may be taken as a broad indication for the hypothesis that labour intensive technique has higher surplus per unit of capital than capital-intensive technique".

(c) Positive association between capital-intensity and output, wages and surplus each per worker would not be established as the "overall evidence is either weak or pretty much conflicting".

He suggests that for India, appropriate technology would be large-sized units with labour-intensive techniques, while small sized units and capital intensive techniques seem to be inappropriate. However, Sandesara mentions several limitations seriously affecting his results. Other important limitations to his study are the following:

(1) Factories employing 20 or more workers on any day and using power only are included in his study. A study intending to analyse the affects of size on economic characteristics of a firm should not have ignored very small-scale units.

(2) Value of capital (working and fixed productive capital) was taken as in the books of the factory which is, by notion, different from the one required in economic [illegible]. studies.

---

[1] He grouped the 29 industries into three categories numbering 12, 10 and 6 each and one industry (Sewing Machines) was eliminated from the analysis.

(3) Depreciation is calculated at the rates allowed by the income tax authorities. This implies depreciation might not have been valued uniformly for all the factories. As the output is value-added by manufacture (gross ex-factory value of the product minus value of fuel and materials used, depreciation etc.), this affects the values of surplus seriously.

(2) and (3) above could very much affect whatever results he obtained and hence not much confidence needs to be kept in the results of this study. While commenting on this study R.B. Sutcliffe[1] mentions that there are other inputs to production than the ones used in this study, and also that larger units require more infrastructural capital which was not accounted here; and this might explain his conclusions. Sutcliffe's comment raises important issues in studying the problem of choice of techniques: what capital to account: total (fixed, working, infrastructural all together) or only fixed or only equipment capital? How to value capital? How to estimate output : at actual utilization or full utilization of the equipment involved in the operation of a technique? These are several problems which may crop up in the empirical verifications about the theory of choice of techniques. Very few studies have attempted to analyse how seriously these issues affect choice of techniques.

1/ R.B. Sutcliffe (1971).

Chatterjee[1] etc. studied this problem for mustard oil industry. The purpose of their study was (a) to find out the problems that crop up in making such enquiries about choice of techniques and (b) to present whatever results are available as illustrations.

They identified techniques in terms of capital labour ratios. Eight units of mustard oil industry were selected for this study, of which two were from Calcutta, one from semiurban surroundings near Calcutta and five from villages. Diverse circumstances about price differences, scales of operation, locality of operation etc. under which these techniques were found to be operating, affected the estimates of capital, costs as well as output of different units. To obviate these troubles the following methods were adopted:

(a) capital figures were presented in 3 ways referring to total capital, total fixed capital, total equipment capital.

(b) Value of capital was estimated in 3 ways: the historical cost, market value and investment value.

(c) all estimates of capital were presented in terms of actual prices as well as on the assumption of a uniform price for all units.

Cost of production was estimated as follows:

(a) cost elements were valued both in terms of actual and constant prices;

(b) certain elements were excluded sometimes;

(c) estimates were made both on the bases of actual utilization and full utilization.

---

[1] Chatterjee (1963).

Output is estimated on the principles of

(a) actual price and constant price;
(b) actual utilization and full utilization.

With the primary data they have collected, mainly the following were calculated with the above mentioned variations:

(a) capital per unit of labour;
(b) capital-output ratios;
(c) surplus-capital ratios;
(d) value-added capital ratios; and
(e) recovery period for various types of capital.

Though the aim of this study is not ambitious, it succeeded in finding out the problems that crop up in making such enquiries about choice of techniques. However, it did not seek to analyse profoundly the conceptual problems involved behind the variations it considered except to present whatever results they have obtained as mere [illegible] illustrations.

A serious shortcoming of the approach behind all the above studies is that it has ignored economies of scale. The calculations about factor proportions and factor-productivity and rate of surplus are assumed to hold true at higher levels of output also, which may not be correct. It is necessary to justify or verify empirically such assumptions before this approach is adopted. The approach based on "production function", to which we pass on next, can be rated an improvement, atleast to the extent of "economies of scale" are concerned.

2.3.2 Approach based on econometric production function

A "production set" describes all technically possible combinations of inputs and the resulting outputs. "Production function" relates the combination of inputs to the maximum output that can be produced with that combination. Hence, conceptually, it presupposes a technical maximization problem within itself. More generally, the production function describes the boundary of the production set (or production surface). The production function corresponds to a given state of technology. It is worthwhile to note the difference between "technology" and "techniques". A given state of technology corresponds to a production function and describes a production surface in the input-output space. Different points on this surface are different techniques. Different technologies mean different production functions. Given a production function, the technique to be selected depends upon the economic enviroment of the world in which the choice is to be made. It is at this point, engineering considerations and economic considerations interact and the problem of optimality turns out to be techno-economic in nature. Hence the production function becomes a binding constraint in the economic analysis of production. The choice of optimal input combination to produce a given output level depends also upon the relative prices of various inputs. This sort of approach led many economists to estimate production functions empirically.

Principal among such works are by Minhas for 24 industries in 19 countries, by Nerlove for U.S.Electricity industry and Kurz and Manne for metal working industry. In all the above studies either CES (Constant Elasticity of Substitution) production function or generalized Cobb Douglas production function (which implies elasticity of substitution between any pair of factors is one) was fitted. Though it is beyond our scope to critically review all these studies, it is of interest to note how these studies remained deficient in solving the questions that have been addressed to, owing to the assumptions involved in them. Let us look into Minhas' study[1] in particular.

The aim of his study includes (1) suggesting empirically usable relations for the analysis of substitution between capital and labour, (2) ascertaining, quantitatively, the differences in the cost of labour and capital in a fairly large number of manufacturing industries and to derive numerical estimates of the elasticity of substitution between the two inputs. The merit of his study lies in obtaining an independent estimate of the elasticity of substitution (σ) rather than inferring it from the mathematical form of production function. Such an indirect method of estimating σ (of a constant elasticity of substitution production function) involves regressing man years of labour per dollar worth of value added on

---

[1] B.S.Minhas (1963).

the wage rate. This method is based on the equivalence, under constant returns to scale, between the logarithmic derivative of the ratio of value added and labour inputs with respect to wage rate and the elasticity of substitution between capital and labour. He used inter-country cross section data in estimating CES production function, separately for 24 industries of 19 countries. T.H.Mayors[1] study shows that estimates based on time series data widely differ from those based on cross section data; and a priori it is impossible to know which of them approximate the actual elasticities. P.K.Bardhan's study[2] also shows that by regressing the output per worker on the wage rate, under certain assumptions, the regression coefficient will overestimate the elasticity of substitution of the ex-ante production function.

Minhas' indirect method of estimating the elasticity of substitution is attractive because a knowledge of the capital data is not required at all. But as pointed out by Leif Johansen[3] "one can relate this to the parameters of the production function only if one is willing to rely on certain assumptions concerning behaviour such as cost minimization under competitive conditions or under other specified types of market situations".

1/ T.H.Mayor (1969).

2/ P.K.Bardhan (1967, 1969).

3/ L.Johansen (1972).

Two of the assumptions usually made for estimating the elasticity of substitution are (a) constant returns to scale and (b) technical progress that occurs is neutral in the Hicksian sense (i.e. capital-labour ratio remains unchanged). However studies by C.S.J.O.OHerlihy[1] for Latin American Textiles Industry and G.K.Boon[2] for three industrial and nonindustrial sectors of Netherlands show that neither of the above assumptions holds true.

The conventional neoclassical theory, on which studies by Minhas, Nerlove etc. rest, most often identifies just two inputs: capital and labour; and treats them as homogeneous. Usually the problem of choice of techniques comes to the surface whenever following types of situations are to be tackled: a specific type of capital is scarce and hence whatever is available should be utilized optimally, particular class of the population (unskilled labour) needs necessarily to be employed and hence given some amount of income directly so that income distribution of the society can be taken care of; particular material like say, cement, should be used to minimum possible level etc. Then the usual production function at an aggregated level is not the relevant tool of analysis.

---

[1] C.S.J.O.OHerlihy (1972).

[2] G.K.Boon (1964).

Another feature of the traditional production function is that a continuous spectrum of techniques is assumed to be available. Though this assumption is one of convenience and no deep problem is involved in treating it as an approximation, this in general is not true. Besides, another disadvantage of the statistical approach involved here is that one is not sure whether the set considered in the analysis of production alternatives is completely exhaustive. It might be a simple reflection of only those techniques which are in vogue at the time of data collection. So conclusions about technological choice based on ex-post data, would only provide out-of-date information about what was already known. Econometric attempts, according to R.Turvey[1], to ascertain the presence and extent of economies of scale in electricity generation, for instance, have been a complete waste of time; and yet economies of scale are substantial in electricity-generation. Hence this approach cannot offer a direct knowledge of different techniques; Such a direct knowledge needs ex-ante data with necessary back-ground of engineering analysis and blue-prints.

Problems of the above nature got quite many applied economists disappointed with the traditional marginal analysis of production functions. Writing on problems of aggregation, Ashok Rudra[2] suggests that engineering production functions using blue-print data might yield

---

1/ R. Turvey (ed.) (1971).

2/ A. Rudra (1969).

better results. Moreover, values of capital and labour obtained through this approach, do not tell anything about the "choice of techniques" in its true sense, but indicate only the totals of these two factors calculated from a mixture of several techniques. But the problem of choice of techniques should be solved at a more basic level concerning not only with inputs and outputs at an aggregated level, but also with the amount and the quality of energy resources and other factors of production required to transform materials (e.g. horsepower, calorific value etc.) and other engineering variables (like safe bearing capacity of the soil, permissible safeload, tolerance limits etc.). This is why "the production function" as Dorfman, Samuelson and Solow[1] say "is a description of the technological conditions of production and the economist takes no direct responsibility for ascertaining it". In fact, Johansen[2] calls for a critical examination and even a reformulation of the very notion of production function because "the crudeness of the concept of production function as it is being used in most econometric research, is accordingly out of proportion with the sophistication of the theories and methods by which it is surrounded".

So, I believe that the traditional econometric approach of setting up a production function eludes and does not necessarily suggest a satisfactory solution of the problem. Let us "discard the concept of production

---

1/ R.Dorfman, P.A.Samuelson, R.Solow, (1958).

2/ L.Johansen (1972).

function (macro as well as micro) altogether and work in the terms of blue-prints or activities ....'[1] taking relevant engineering considerations also into account. Let us take up the engineering approach.

2.3.3 Engineering approach based on ex-ante technological data

The list of advantages of approaching the problem of choice of techniques with technical background is long and it includes mainly the following (see Walters)[2]:

The range of applicability of engineering production functions, derived directly from technological data, is clearly known in advance. Hence the responsibility of ascertaining the optimum technique can be owned. Because the data used are technological data rather than statistical observations the results of technological progress[3] can be easily incorporated. As the data are based on technological analysis, the results are not confined to narrow range of ex-post observations unlike in econometric production functions based on cross section and time series data. Due to the same reason, precise information for constructing input-output tables can be synthesised and hence more accurate plant cost curves can be drawn. Knowledge of these input-output tables is very important while allocating the scarce resources to various sectors of the economy.

---

[1] T.N. Srinivasan (1969).

[2] A.A. Walters (1963).

[3] W.Z. Hirsch (1952, 1956).

Walters lists two more differences of engineering production function from traditional production functions. First, as the engineering data reflects the most efficiently managed process or average experience, enterpreneurship exists inherently in these data itself and is not explicitly accounted. Secondly, a firm operates both technical and non-technical activities. Only the former activities are covered in engineering production functions and the latter activities like selling goods are not considered. Hence engineering production function is not a comprehensive production function of the firm. However, one has to note that these are only differences between the two approaches and not relative merits of one over the other.

Engineering production functions are relatively more difficult to establish atleast in view of the following two problems: First, usually the inputs are often specified in terms of engineering variables like calorific value, safe bearing capacity of the soil etc. As the optimum technique selection is a technoeconomic decision, there must be a way to connect these engineering variables to economic variables. For example, calorific value may have to linked with the nature and amount of fuel to be used; safe bearing capacity to number of bricks and amount of cement, sand etc. required. Second problem arises due to following reasons: a plant is considered to comprise several processes. Naturally engineering analysis of production starts from process level on wards, finally to be synthesised into a plant production function. Such synthesis is more difficult if the processes are all not independent and additive.

Many engineering studies seem to exhibit increasing returns to scale in general. However, as Walters points out, process and plant functions are not suitable for testing hypothesis about economies of scale of the firm. Costs of non-technical activities like administration, which are not included in these functions, may offset increasing returns to a process of the plant or firm.

Despite several merits of this approach, listed above, it is regretful that adoption of this approach in economics is still in its incipient stage. Very few studies have been made so far. Chenery's analysis for gas transmission in pipelines[1], Kurz and Manne's analysis for capital-labour substitution in metal machining, Vernon Smith's analysis for electrical transmission and heat transmission etc.[2] and a few others are the lone examples in this area of research. As it is beyond our scope to review critically all these studies here, let us be content with looking into the former two studies.

Two possible approaches in the direction of setting up 'process and production functions from engineering data", according to Chenery, are "experimental

---

1/ H.B.Chenery (1949, 1953).

2/ V.L.Smith (1961).

thod" (i.e. a cut and try approach) and "analytical method" n idealized system). Former one is based on extrapolation ng past statistics observed on similar systems. Operating ta on old plants are used to design a new plant, not cessarily backed by a satisfactory theory of the relation the different elements to the process taking place. The alytical method is based on laboratory experimentation. the process under consideration is first reduced to an deal system, this can be obtained as a way of mathematical rivation from the basic physical, chemical and engineering rmulae. However, since the analytical results lead to onstruction of an experimental model, to be modified on the asis of operating tests, final result often comprises both the methods. Chenery obtained two forms of the production function. One expresses (gas transmitted) output as a function of horsepower and tons of pipe, derived purely from thermodynamic considerations. The other one gives output as function of capital and current inputs. Former one relates the output to engineering variables, while the latter to economic variables. There could be a possibility of substitution between horsepower of the compressor and pipe line diameter. But such a possibility could exist only narrowly between capital and current inputs. This is very easy to understand. Smaller the pipeline diameter, greater the capacity of the compressor required; and any minor variations between these two might not significantly vary the economic variables. However, Smith[1] comments on Chenery's work that it does not make an explicit analysis of the energy input to the compressor process, which could have yielded substitution possibilities between current inputs also.

However, this type of approach cannot be adopted in the current project. Construction is a vastly ramified task; details of its each and every process may have to be looked into to get an optimal solution with respect to any objective. An experimental approach may not be possible because data on old systems may not be applicable to new systems, though the old and new systems are similar in nature. For example, data relating to a house built with bricks are not applicable to a house built with precast concrete blocks, though basically it is a 'house' that is being built. An analytical approach ecomes a hopeless and cumbersome task with enormous civil ngineering calculations involved. Besides, this might lead o building several alternative types of 'pilot' or experimental' houses, which might be a wastage sometimes.

The other study by Kurz and Manne[2] is with regard to engineering estimates of capital labour substitution in etal machining". They considered in this analysis a inite number of engineering tasks involving four general ttributes: geometrical shape, size of piece, tolerance d lot size. They have observations on a set of machine

---

[1] V.L.Smith (1961).

[2] Kurz and Manne (1963).

ools regarding their mode of operation of the above ngineering tasks. For each task they plotted output per orker versus investment per worker; and eliminated thereby the points corresponding to inefficient machines. The criterion followed in doing so is that if in the performance of a given task, "one machine tool had a higher investment cost and not a higher output than a second achine tool, the first was said to be inefficient one and was deleted from" their analysis. Thus they censored 1143 estimates, supplied by Markovitz and Rowe to retain only 290 such estimates. For these points, again Cobb Douglas and CES type of econometric production functions were estimated.

The merit of their study lies in estimating the coefficients for separate engineering tasks, so that it is easy to formulate a production function for any specified product involving the former tasks, simply by picking up the corresponding estimates. However, in the literature[1] on production functions, the Kurz and Manne criterion for elimination of inefficient points and also their measurement of capital have been criticized. Leif Johansen[2] shows that by plotting capital per unit of output versus labour per unit of output instead of output per worker versus investment per worker, the efficient points in the

---

1/ E.G. Furubotn (1965). See also L.B.Lave (1966).

2/ L. Johansen (1972).

latter plot may turn out to be inefficient in the former. However, it is to be noted that such an alternative way of identifying the efficient points would hardly alter the over all results obtained by them.

Besides, though the specification of the production functions in Kurz and Manne' study involves some engineering variables (like geometric shape, tolerance, etc.) other than the usual economic variables (capital, labour as homogeneous units), the essential approach in setting up the function is again based on statistical techniques. The analysis took engineering considerations into account only at a somewhat crude level. Thus it is more of an econometric production function and less of an approach answering Leif Johansen's call mentioned earlier. And, as Dorfman etc.[1] put it "... the production function short circuits certain aspects of the problem that the engineer cannot afford to neglect. The economist cannot afford to neglect them either when he wants to look inside the firm. Moreover, there is some advantage in talking the engineers' language. For, among other things, this is the language in which engineering and accounting data are expressed. This is the point of view taken in linear programming".

1/ R.Dorfman et. al. (1958).

2.4 Concluding observations

From the above, not only the importance of engineering considerations but also the usefulness of linear programming in the choice of techniques problem, is to be noted. It is interesting to note that Chenery[1] also advocated adoption of programming approach in solving the problem of allocation of resources and selection of techniques. We conclude that in solving the problem of appropriate technology in buildings and roads construction, mathematical programming methodology should be adopted and engineering considerations should be used to identify the alternative techniques.

1/ H.B. Chenery (1961).

Chapter III

REVIEW OF LITERATURE ON CONSTRUCTION SECTOR

3.1 Literature on Building Construction

In this chapter, we will review the existing literature on appropriate technology for the construction sector in the Indian economy. Of the very few studies available on this problem, the following two are important: "Performance Approach to Cost Reduction in Building Construction" - report of the expert committee set up by Government of Kerala in January 1974[1], and the report of the working group on building and road construction by Appropriate Technical Cell, Ministry of Industrial Development, 1971. Above two are related to building construction, about which we discuss first. Road construction part is discussed later.

3.1.1 "Expert Committee Report"

The report of the expert committee set up by the Kerala Government is thoroughly practical in its approach towards the problem. It starts with a basic principle that any reform, rethinking, replanning and redesigning in solving this problem of choice of techniques must start at the top and spread through all strata of the society. The objective was to select techniques which result in saving on national cost and not necessarily on private costs. To achieve the objective of selecting only those techniques

---

1/ K.S.Parikh et. al. (1974).

requring no large additional investments or rare skills or mechanisation they concentrated on "materials which are locally made or locally available in abundance or which can be made by small scale manufacturing plants spread throughout the state and for which the process of manufacturing is labour-intensive, capital-saving and fuel-saving". Thus scarce material resources such as cement, steel, etc. can be conserved.

After a careful thought over climatological considerations, this report of the expert committee (E.C.R. henceforth) concluded that Kerala should have buildings light in weight and colour, with adequate ventilation facilities and protecting measures for walls.

Three suggestions made by E.C.R. are worth noting:

(a) Stone work should be preferred to brickwork as Kerala abounds in granite and allied hard stones.

(b) Second rate countrywoods can be used as structural material with appropriate seasoning and treatment.

(c) Lime should be preferred to cement in building construction.

The issues involved in the substitution of lime for cement are both technological and economic.

Technologically lime can replace cement to a certain extent in mortars[1] without affecting the safety

---

[1] Mortar is the plastic and homogeneous product obtained by mixing appropriately sand, cement, lime, surkhi etc. with water in specified proportions.

of the structure. Infact additional advantages are obtained by the use of lime in building-mortars: (1) Increased plasticity and workability. (2) More flexibility under stress. (3) High bond strength. (4) Ease of retempering. (5) Less efflorescence. (6) Lighter coloured mortar and (7) Autogenous healing. Besides, lime is the oldest binder and plasticizer. Its earliest use was in 4000 B.C. when it was used in Egypt for plastering the world famous pyramids. It was made use of in the royal constructions of Mughal empire in India. Though lime can replace cement in mortar, plasters and plain concrete, only cement can be used for reinforced concrete works as lime would corrode the steel reinforcement.

The economic implications of lime-cement substitution seem to be many. Table 3.1 gives a cost comparison of equivalent mortars using cement, cement-lime and lime and surkhi[1]. It can be observed that switching over to lime or lime and surkhi from cement will save on fixed investment, fuel consumption and electricity too. However, in manufacturing as well as in actual use in construction, lime and allied mortars are believed to require more labour than what cement does. Thus substitution of lime etc. for cement may be even more welcome because that would contribute more employment to the economy while still costing less.

1/ Surkhi is made by grinding burnt-bricks to powder.

Table 3.1: Cost Comparison of Equivalent Mortars Using Cement, Cement and Lime, and Lime and Surkhi

	1:6 cement sand motar	1:2:9 cement lime sand motar	1:1:5 lime surkhi sand motar	
Item	cost* of producing one million tonnes of cement per year	cost of producing 1.33million tonnes of lime (*) per year	cost of producing 0.56 million tonnes of lime (***) per year	cost of producing 1.20 million tonnes of surkhi (**) per year
1. Fixed Investment	Rs. 40-45 crores with (15%) foreign exchange	Rs. 40 lakhs	Rs. 18 lakhs	Rs. 8.2 crores to burn and Rs. 4.1 crores to grind
2. Fuel Consumption				
a. Fuel oil	1,50000 tonnes	1,40000 tonnes	65000 tonnes	
b. Coal (6000 BTu)		or 3,30000 tonnes	or 1,50000 tonnes	2,40000 tonnes
c. Electricity	$80x10^{6}$ Kwh			$40x10^{6}$ Kwh for grinding

* For a large scale modern plant.

*) For small scale sector operation.

**) When 1:2:9 cement:lime:sand mortar (by volume) is used instead of 1:6 cement:sand mortar (by volume) 1.33 tonnes of lime is required to replace a tonne of cement.

***) When 1:1:5 lime surkhi sand by weight of (1:2:8 lime:surkhi:sand) mortar is used instead of 1:6 cement:sand mortar 0.60 tonnes of lime and 1.20 tonnes of surkhi is required to replace one tonne of cement.

Note: (1) For equivalence of these mortars see I.S.Code 1439. Reproduced from: "Performance Approach to Cost Reduction in Building Construction" - page 16.

ECR recommends many small or medium sized lime kilns because "the economies of scale are not very dominant for the lime kilns and small scale production of lime can be economically undertaken". ECR also recommends that hand moulded bricks should be preferred to mechanised bricks as it provides more employment and costs less see Table 1 3.2 which gives investment cost of production and labour required for alternative bricks and substitutes.

After an analysis of building materials, ECR examined various construction techniques. It observed that load bearing masonary walls are the most economical and hence "there is no case for the use of reinforced concrete framed structures for normal buildings for three or four storeyed buildings in Kerala". It also recommends $4\frac{1}{2}$" brick walls which "can be made to satisfy all the requirements of strength, durability, weather resistence and climatic comfort generally expected by people". For roof work it suggests waffle slab filled with Mangalore tiles as the cheapest and easiest to adopt. Replacement of cement in all plasters and mortars by lime and surkhi mixtures is insisted. Other suggestions include brick jali walls as windows, windows with minimum need for lintels, frameless doors (if frame is necessary concrete frame is cheaper than timber one), replacement of concrete base by brickbat base pavings for all except for heavy duty floors. All these

Table 3.2: Investment Cost of Production and Labour required for alternative bricks and substitutes

Material	Investment for a capacity of ten million bricks a year (Rs. in lakhs)	Foreign Exchange (Rs. in lakhs)	Cost of Production in Rs.per 1000 bricks	Total No.of Persons employed	Remarks
1.Hand Moulded bricks	3-4	0	35	300	Buildings upto 3 storeys
2,Machine-moulded bricks	15	3	80	75	Buildings upto 5 storeys
3.Sandlime bricks	25	12	80	40	Fuel required is 1/3 of that for clay bricks
4.Cellular concrete blocks	50	21	170*	60	Buildings upto 4 storeys. No fuel

No agricultural land is required for 3 and 4

* Price per 2 cu.m.which is equivalent to 1000 bricks.

Source: Rao,A.V.R., Masonry Blocks for Building Construction
Journal of N.B.O., Vol.XVI, No.2, October 1971.

Reproduced from:" Performance Approach to Cost Reduction in Building Construction."

suggestions are claimed to be consistent with the provisions of the National Building Code. Percentage range of overall saving on total cost is estimated for each stage of the construction separately; and it was found that the overall saving can be anywhere from 10.6 % to 32.05 % depending upon the mix of suggestions adopted.

The drawback of this report is its partial approach towards the problem. First it analysed the selection of building materials and then the construction techniques. Again when these techniques are evaluated, each stage of the construction is picked out and then the corresponding techniques are analysed. This would be alright if only the stages of the construction (foundation, basement, superstructure, walls, roofs etc.) are all independent, and techniques selected in any of the stages do not depend upon the ones selected in any other. But this is not true in building construction. Atleast, some of the stages have such interdependence. To resolve these difficulties, an integrated approach involving a simultaneous evaluation of the alternative techniques in all the stages is needed. A systems approach based on activity-analysis and a multi-stage production programming model should have provided such an integrated analysis and would be preferable for evaluating the substitution possibilities among several building materials.

Even the partial approach adopted by ECR is incomplete. A thorough cost-analysis of each and every alternative is missing. This could have been done, for all the alternatives in two ways: (a) in terms of the materials and labour involved i.e. in physical units; (b) in terms of rupees i.e. in monetary units. This analysis was done at an aggregated level, except in the case of various roofing systems where some disaggregated details were shown (page 33, ECR). Another shortcoming, though ECR could have done nothing about it, is regarding the institutional factors. Aesthetic sense, latest fashion, doubts about the safety of the building etc. play quite an important role in the selection of construction techniques. Mangalore tile roofing is one place where ECR is conscious of this issue. Suggestion of different types of houses, also is due to this consideration. Though $4\frac{1}{2}$" load bearing walls are structurally adequate, load factors are given such an exaggerated importance in building construction, that even Indian Standards Institution in their "Building Byelaws" specify that single storey houses must have 9" thick out side walls. However, to prove that all the suggestions by ECR are technically sound, the report presents all the required engineering calculations in an appendix at the end of it.

3.1.3 "Report on Building Construction"

Next, we pass on to "Report on Building Construction" (RBC henceforth) by Appropriate Technical Cell of Ministry of Industrial Development. It starts with explaining the status of building construction in India, and various considerations that led to establish several building research centres in India. Then it gave a detailed account of several research results obtained independently by these research centres. Among these results, the working group behind RBC identified certain areas for implementing the "appropriate building technology". Some of them are taken up below:

(i) Bricks: RBC expressed the need for modernising the manufacture of bricks. It mentioned in this connection about a brick-making machine and high draught brick kiln process developed by Central Building Research Institute, Roorkee. Apparently a semimechanised brick plant incorporating brick-machine and high draught kiln process would fulfil the requirements of modern brick making.

(ii) Lime, Surkhi: Improved methods of manufacture of building-lime and surkhi have been argued for. Rectangular "bhatties" in which generally lime is burnt, causes waste of heat and also produces lime of poor quality. An improved lime kiln designed and developed by CBRI for burning lime successfully at stipulated temperatures is recommended.

(iii) High Strength Deformed Bars: Reinforcements with these bars will save on steel upto 30% . Hence increase in their production is sought, because at present these are produced only to a limited extent.

Other suggestions include: (a) procurement, proper seasoning, treatment and marketing of secondary species of building-timbers and integrated mills providing sawing, seasoning and manufacture of finished joinery products, (b) determination of locations for setting up plants for new materials like light weight aggregates, sand-lime bricks and cellular concrete.

RBC's suggestions regarding construction techniques include:

Adoption of National Building Code by all municipalities is stressed. This code "contains a synthesis of the latest technology and advancement in the field of planning, designing and construction of buildings and incorporates over 600 specifications of building materials and 120 codes of practices brought out by the Indian Standards Institution". It provides the required bye-laws facilitating the use of new materials and construction techniques.

It recommended improved methods of bricklaying plastering etc. and training the artisans for enhancing the productivity of labour. It also recommended the introduction of modular coordination and standardisation in the building construction. It suggests full prefabrication in selected areas for "large scale and long range housing programmes". Precast R.C.roofing units such as cored units, channel units, cellular units and waffle units evolved by CBRI would save steel and cement substantially. Besides they facilitate mass scale production to standard sizes.

It argued for adopting partial prefabrication (use of standard joinery and standardised flooring and roofing components, lintels, staircases, shelves etc.) and avoiding framed structures upto four stories by using better quality bricks or other substitutes, walling materials like c.c. blocks, cellular concrete, sand-lime bricks etc.

RBC identified certain areas for implementing the appropriate technology from the point of view of materials and techniques for rural housing. In this respect, RBC like ECR argues for adopting local materials such as bamboos, thatch, mud etc. However, as these constructions are prone to be damaged by rains etc. such constructions should be improved by soil stabilization. In the end it suggests for setting up working groups on (i) urban housing construction techniques, (ii) industrial building methods, (iii) implementation of National Building Code, (iv) utilization of industrial and agricultural wastes and (v) rural housing. It recommended a 100 percent grant-in-aid for the agencies sponsoring experimentation/demonstration in building projects.

The report has certain limitations: First of all, nowhere in this report is specified regarding, with respect to what objective the technology is supposed to be "appropriate". Lot of confusion seems to have prevailed. The techniques and hence the materials selected do depend upon whether one is minimising the cost of construction or maximizing the employment, or reducing the time taken for construction etc. The objective of the study is never stated clearly.

(ii) Though not all, many of the suggestions by RBC are in agreement with suggestions by ECR. However they differ regarding the manufacture of bricks. Unfortunately, RBC report did not include any economic analysis on mechanised brick plants. Hence RBC's recommendation for modernising brick manufacturing is not acceptable in the absence of such calculations.

(iii) Some of the recommendations by RBC appear to be based on technical rather than economic considerations. RBC recommended the prefabrication (fully or partially) technology, in building construction in view of its speed of completion and mass scale production of prefabricated units. But the economic study of prefabrication has not been done. In fact it says "the optimum scale of operation and number of houses to be constructed employing prefabricated building techniques at economical cost should be determined, considering whether on site prefabrication or off-site prefabrication would be advantageous". Recommendation of any process well before such cost calculations seems to be hasty.

(iv) Like ECR, RBC's approach towards the problem is also partial. It also considered building materials separately; and then each area of the construction separately for evaluating the techniques. It also lacked a thorough cost-analysis of various techniques. Hence, all the comments ade with respect to ECR, calling for an integrated approach involving systems - analysis, apply here also. Broad statements like cost-reduction, saving on cement and steel, ncrease in the productivity may not enlighten as much as nformation with precise quantitative details would do.

(v) Another shortcoming is that the price-information egarding certain machinery is vague; the relevant year is ever specified.

(vi) RBC's suggestions regarding the follow-up action or implementing the appropriate technology should be elcomed. Peoplein this country seem to be unaware of cheap onstruction techniques, judging from the present day ractices. Hence there is need for communicating and isseminating various aspects of construction.

.2 Literature on Road Construction

On road construction the following **three are notable** orks: "Cost of road construction" published by The Indian oncrete Journal (October 1973) and "Appropriate Technology n Road Construction" by **Appropriate Technical Cell, Ministry** of Industrial Development" (1975), and "Employment in Road Transport and Road Construction" by National Council of Applied Economic Research (NCAER) New Delhi(1974). These are briefly reviewed below:

3.2.1 "Cost of Road Construction"

The article "Cost of Road Construction" by the Concrete Association of India is purely technical in nature. It considers the two soil categories with CBR[1] values of 2% and 7% . The details of design and cost for flexible and rigid pavements[2] are worked out according to the guidelines suggested by Indian Roads Congress (IRC) and UK Road Note 29. The entire analysis corresponding to the two soil categories is done with respect to two values of commercial vehicles per day: 500 and 1500. The details are presented for all the different stages of the road starting from the preparation of subgrade and also according to the zone-wise (different areas of the country were divided into four zones[3]). The estimates of cost include present values of investment and the recurring costs such as annual maintenance and renewal

---

[1] CBR (California Bearing Ratio), a number expressed in terms of percentages, indicates nature of the soil where the road is built.

[2] Bituminous pavements are flexible whereas concrete pavements are rigid.

[3] Zone I includes Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, Delhi, Rajasthan, Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradesh, Karnataka, Tamilnadu, Kerala.

Zone II includes Assam, Manipur, Nagaland.

Zone III includes Uttar Pradesh, Bihar, Orissa.

Zone IV includes West Bengal, Bihar, Uttar Pradesh.

of surfacing at various periods. The cumulative costs upto 40 years and at prescribed periods of 15, 20, 30 years over a range of interest-rates are presented. The conclusions of this analysis are:

(i) CBR: 2%, 500 comm. vehicles/day: rigid pavements are cheaper in comparison with IRC guidelines at 20 years in zones III and IV at all rates of interest. In comparison to Road Note 29, costs of rigid pavements are cheaper at 20 years in zone I, at 15 years in zone II and even in initial costs in zones III and IV.

(ii) CBR: 2%, 1500 comm. vehicles/day: rigid pavements are cheaper in comparison to IRC guidelines at 20 years in Zone III for all rates of interest, and at 15 years in zone IV. In comprison to Road Note 29, costs of rigid pavements are cheaper in initial costs in all four zones for all rates of interest.

(iii) CBR: 7%, 500 comm. vehicles/day: rigid pavements are cheaper in comparison to IRC guidelines at 20 years with 8 and 10 percent interest rates in zonesIII and IV, and at 30 years in zone IV for all interest rates. n comparison to Road Note 29 rigid pavements are cheaper t 20 and 15 years in zones I and II respectively, and n initial costs in zones III and IV for all rates of nterest.

(iv) CBR: 7%, 1500 comm. vehicles/day: rigid avements are economical in comparison to IRC guidelines at 20 and 30 years in zone III, and at 20 years in zone IV for interest rate of 8% and 10% respectively, and at 30 and 20 years at 8% interest rate in zones I and II respectively. In comparison to Road Note 29, rigid pavements are cheaper in initial costs in all the zones at all interest rates.

Though technically sound, the above analysis ignored certain important noneconomic factors like level of the total employment generated, the amount of cement and bitumen etc. required in load construction. Secondly, various alternative techniques have not been considered. Entire analysis is based upon one technique each for flexible pavements and rigid pavements.

3.2.2 '<u>Appropriate Technology in Road Construction</u>'

Next, we pass on to review the "Appropriate Technology in Road Construction" by Ministry of Industrial Development. It defines an appropriate technology to be "a technology which is more sound than that prevalent in the past and which results in better quality of construction with the requisite degree of durability, structural strength and economy so as to give the users an appropriate pavement with the required serviceability". Later, it splits the research efforts in the context of road construction in India into

(a) salient achievements in evolving new techniques,

(b) important findings of applied highway research,

(c) utilization of locally available material,

(d) development of new tools and appliances and

(e) patented processes, materials and devices.

The suggested new techniques include lime stabilized soil sub-bases, composite pavements, bricksandwiched concrete pavements, burnt clay puzzolanas, prestressed concrete pavements. Scientific use of locally available materials like soil, moorum and aggregates like kankar, laterite and shale etc, either in their natural state or in combination with other stabilizing materials is suggested. Rest of the report contains information about training facilities for engineers, dissemination of the knowledge and implementation of all the suggestions.

This report is purely descriptive in regard to the various techniques suggested and no cost-analysis at all is presented. Hence no comments in particular are made.

3.2.3 "Employment in Road Transport and Road Construction"

Two of the chapters of this study by NCAER relate to road-construction in India. This study is aimed at estimating the employment level that can be generated in constructing different types of roads for a given total outlay of expenditure on road-construction. The methodology adopted is as follows:

"To start with, we have the total cost of a road project. This can be further broken up into several components of cost, but our main concern is with the wage and nonwage components. This labour cost (which is the same as total wage bill for the project) is the monetary value of the labour input in the project. Given the wage rate, labour input in physical terms can be worked out as the final step in our computation".

Different roads have been classified into: national highways (plains), state highways (plain and hills), district roads (plains and hills) and village roads. Due to regional variations, no standard cost of construction of any particular type of road could be worked out as a representative for the entire country. A range of costs rather than one cost for a given type of road is arrived at. All costs (at 1972 prices) are expressed for one kilometre of road. Cost estimates do not include land cost and relate only to the cost of construction. Table 3.3 below gives the information on these costs:

Of the total cost of construction of any type of road only 68% is assumed to be due to labour-input. Assuming that the ratio of total wages received by skilled and unskilled workmen is about 1:36 to 1:39 for earthwork, 1:7 for black topping and 1:4 for cross drainage works, the total wage bill is split into that for the skilled and unskilled categories. Now the mandays of labour required for one kilometre of road are worked out assuming that Rs. 5 and 15 are the wage rates

Table 3.3

Cost of construction (Range) of one kilometre of Road for different phases of work by Type of Road (Rs.'000)

Type of Road	Phase of work							
	Earthwork		Black topping(asphalting)		Cross drainage work		Total	
	from	to	from	to	from	to	from	to
National Highway (plains)	125	136	105	115	42	44	272	295
State Highways (plains)	76	83	61	67	28	30	165	180
State Highways (Hills)	75	84	63	70	37	41	175	195
District Roads (plains)	68	75	54	59	29	31	151	164
District Roads (Hills)	68	73	57	61	33	36	158	170
Village Roads (plains)	35	45	-	-	-	-	35	45

per day for unskilled and skilled workers respectively. Table 3.4 gives this information for national highways (plains) and state highways (plains). (Details corresponding to other types of roads can be had from NCAER (1974)).

Finally this work concludes that the employment content will be of the order of 5000 to 5200 man years per one crore rupees of investment (or outlay) for construction of roads except village roads. For village roads this estimate is supposed to be 7200 man years.

The limitations of this report include:

(i) Substitution possibilities between labour, other material and capital inputs are not analysed. The cost estimates appear to correspond to only one technique of construction for

Table 3.4

Skilled and Unskilled Mandays Required (range) for construction of one kilometre of Road for Different Phases of Work by Type of Road

Type of road	Phases of work							
	Earthwork		Black topping		Cross drainage		Total	
Labour category	from	to	from	to	from	to	from	to
National Highways (Plains)								
Skilled	200	220	434	473	280	293	914	986
Unskilled	21800	23740	9100	9980	3360	3520	34260	37240
Total	22000	23960	9534	10453	3640	3813	35174	38226
State Highways (plains)								
Skilled	113	127	250	267	187	200	550	594
Unskilled	13260	14620	5250	5600	2240	2400	20750	22620
Total	13373	14747	5500	5867	2427	2600	21300	23214

different types of roads mentioned in table 3.3. Hence the final estimates given by this report, of the employment content that can be generated for a given expenditure outlay of road-construction cannot be asserted to be the maximum possible level.

(ii) Precise estimation of the total cost of road construction is absent. To start with itself, one has the total cost of a road project, the wage content of which is worked back based on some assumptions. Estimates of the employment content might be sensitive to such assumptions (especially wage rates) and hence they are more arbitrary than precise.

Chapter IV

THE ANALYTICAL PROGRAMMING MODEL

4.1 Introduction

A production set describes all technologically possible combinations of inputs and outputs. A production function relates the combination of inputs to the maximum output that can be produced with that combination. Hence, conceptually it presupposes a technical maximization problem within itself. It means that the corresponding isoquant describes only technologically efficient alternative combinations of inputs to produce a given output. "Optimality" comes into the picture after "efficiency". The choice of the optimal input combination to produce a given output level depends upon the relative prices of the various inputs.

That implies, tracing out the production function or the corresponding isoquant is to weed out all the inefficient input combinations and to identify only the technologically efficient ones. In an optimizing programming model based on activity analysis the optimal point with respect to a given objective is also an efficient one and the efficiency fronteir can be identified from the production set by finding the optimal input-combinations for all the possible variations of their relative prices. But this would be a cumbersome task, if the exercise involves several inputs. In fact, in our model, there are sixteen primary inputs and six classes of labour.

However, in many cases we are not interested in varying the prices of all these factors except a few of them. In other words, we are not concerned with the entire production function but only a part of it. Thus it becomes a manageable task to trace out the relevant part of the production function by observing the optimal points directly from the production set itself, through a programming model. It should be noted that using this programming model we are capable of answering all the questions that the traditional production function analysis does and more. Though the complete (engineering) production function is not traced, one can always get a new solution of the model when conditions change.

4.2 Outline of the Model for Building and Road Construction

A model based on linear programming is presented below for tracing out the relevant part of the engineering production function and identifying the appropriate technology in building construction (single storey houses) and road-construction. An appropriate technology consists of the optimal levels of various alternative activities available for construction of a building or a road with respect to specified objectives and economic constraints which are appropriate for the country.

There are two types of activities (or choice variables) in the model: activities related to primary resources required in producing the intermediate inputs required in building construction and road construction and the activities related to several technical (or production) alternatives. Primary resources include capital, fuel (coal and electricity), limestone, gypsum etc. which are required in the production of cement, bricks, lime steel etc. As explained in Chapter I, output selection in this exercise (one house or a kilometre of national highway) is based on its functional utility rather than on its technical specifications. Generally variations in input levels from technique to technique are considered only with respect to capital and labour but not with respect to intermediate inputs, in producing a technically specified output. In this case the levels of the material inputs other than capital and labour remain same for all the techniques and hence can be ignored. But in producing an output selected on the basis of its functional utility, the intermediate inputs also vary (as in the case of brick-house and stone-house) from technique to technique and hence the material inputs other than capital and labour cannot be ignored. These must be accounted in full detail for exploiting the substitution possibilities between them. The resource activities mentioned above correspond to all these primary resource inputs.

The levels of the resource and production activities are to be determined such that the overall cost of operating them is the minimum possible, satisfying the following constraints:

(a) feasibility of the programme is assured by conforming to the technical specifications,

(b) needed output is produced at each stage of the production,

(c) resource requirements are met with,

(d) desired levels of total, direct and indirect employments according to different wage group are generated, and

(e) no activity is operated at a negative level.

4.3 Definitions and Notations Used for Variables

The following table explains the definitions and notations of different coefficients, variables and parameters appearing in the analytical models for building construction and road construction.

Notation	Definition	Variables/parameters
Y	Vector of primary resources indicating the resource requirements	Variables
X	Vector of production activities indicating the technical alternative of production	Variables
A	Intermediate input requirement Matrix (a_{ij}=requirement of ith input to produce unit output of jth activity)	Parameters
B	Primary resource Matrix converting intermediate inputs into primary resource (b_{pi} = requirement of pth primary factor to produce unit output of ith intermediate input)	Parameters

L	Total labour requirement vector (l_j= total labour required by jth activity for its unit operation	Parameters
D	Direct labour requirement Matrix (d_{qj} =labour corresponding to qth income class, directly employed by jth activity for its unit operation).	Parameters
S	Labour Matrix specifying the labour requirements for unit production of each of the intermediate inputs (s_{qi}=qth wage group labour required to produce unit output of ith intermediate input).	Parameters
N	Indirect labour requirement Matrix (n_{qj}=requirement of labour corresponding to qth wage group indirectly employed by jth activity for its unit operations).	Parameters
Q	Output coefficients Matrix (q_{ij}= output coefficient of ith activity in jth stage).	Parameters derived by engineering calculations.
P.	Matrix whose elements are derived from engineering and technical considerations to ensure a proper and feasible combination of technical alternatives.	Parameters
C	Vector of cost coefficients (in the objective function) corresponding to t_j and x_j in T and X respectively .	Parameters
I	Identity matrix of approrpiate size	–
E_t	Desired total (direct + indirect) employment	Parameters
E	Vector specifying desired levels of employment of various earning classes	Parameters

Y	Vector specifying the necessary output at each stage of the construction of building or a road.	Parameters derived by engineering calculations

---

4.4 Assumptions and their Realism

Assumptions: The following assumptions are made in writing out the model:

(1) Levels of the activities are perfectly divisible.

(2) Total cost of the programme is the sum of the costs of the individual activities employed at different stages of the production i.e.

$$C(X_1, X_2, X_3, \ldots, X_n) = \sum_i C_i X_i$$

(3) Entire system of the constraints as well as the objective function is linear.

(4) No direct fixed capital is employed by any activity in building construction.

Realism of the Assumptions: First three assumptions are required for applying linear programming. All the above assumptions are fairly realistic in the context of building and road construction in India. As an example, 1:2:4 cement concrete work can be done in any fraction required, like 1 cu.m or 2 cu.m or 20/3 cu.m or 80/6 cu.m etc. Similarly if 1 cu.m. of such work costs say Rs. X/- it is true in construction that Q cu.m. of the same work costs Rs. QX/-. Also total cost of the construction is equal to the sum of its constituent activities like foundation, walls, roof etc.

Fourth assumption is also reasonable in the sector of building construction in the Indian economy. This sector is not yet mechanised, even to a minor level. The result is that the only direct capital is a few trowels, hammers, buckets etc. which contribute little to the cost of construction and hence can be ignored. So the assumption that direct capital involved in the operation of any activity in the building construction is nil, is close to reality. However, this is not true in road construction for which such an assumption is not made.

4.5 Model for Building Construction

4.5.1 Resource Constraints: The process of building construction is split into M stages, as follows (see plates 1 & 2):

Stage 1 : Construction or laying the foundation bed for load bearing walls
Stage 2 : Construction or laying the foundation bed for partition walls
Stage 3 : Construction of foundation for load bearing walls
Stage 4 : Construction of foundation for partition walls
Stage 5 : Construction of load bearing walls
Stage 6 : Construction of partition walls
Stage 7 : Construction of roof
Stage 8 : Construction of flooring on the ground
Stage 9 : External plastering
Stage 10: Internal plastering.

The stages are numbered such that the higher numbered stage usually follows the corresponding lower number stage.

In each of the above M stages ($M = 10$), alternative techniques are available. Let M_s be the number of such alternative techniques available in sth stage; and

$$n = \sum_{s=1}^{s=M=10} M_s$$

Let us designate all the levels of the alternative activities (or techniques) from all the above ten stages taken together as follows:

$$(X_1, X_2, X_3, \ldots, X_j \ldots X_n) = X'_{1xn}$$

We have an input-matrix called A (of order mxn), whose elements "a_{ij}"s give the following information:

a_{ij} = requirement of ith input* to produce unit output of jth activity ($i=1,\ldots,m$ and $j=1,\ldots,n$)

Let

$$AX = R \qquad (1)$$

where the vector R (of order mx1) gives the required total amounts of all the "m" (intermediate) inputs, to run the production activities at a level of X.

But these 'm' inputs in turn are to be produced first, before they are available for building construction. Such a production essentially requires capital and labour and other primary material inputs such as fuels, ores etc. Let these except labour be known as "primary factors" or "primary resources". We have accounted for such indirect labour separately later. We have a matrix B(of order kxm),

---

* These are intermediate inputs in the sense, first they have to be produced before being available for construction.

whose elements 'b_{pi}''s give the following information:

b_{pi} = requirement of pth primary factor to produce unit output of ith intermediate input ($p = 1,\ldots,k$ and $i = 1,\ldots,m$)

Now BR should give the required total amounts of all the k primary factors (capital, fuel etc.) for producing the intermediate inputs R. Let these amounts be represented by a vector T (of order kx1), and these must be provided by the economy. Then we can write the following:

$$BR = T \tag{2}$$

Now given (1) and (2) , i.e.

$$AX = R \quad \text{and}$$
$$BR = T$$

We write

$$BAX = T$$

or $$BAX - T = 0$$

or $$IT - BAX = 0 \tag{3}$$

where I is an identity matrix of the order kxk.

The elements in T and X vectors are the variables in our model, which appear in the objective function explained later. Equation (3) is the first set of constraints in the model.

4.5.2 Employment Constraints

4.5.2.1 Direct Labour: It is to be emphasised that labour force is not included in both A and B matrices above. The present model will take several types of labour skilled workers, semi-skilled workers, unskilled workers etc. depending upon their earnings) into account. We have an employment matrix D whose elements "d_{qj}"s give the following information:

d_{qj} = requirement of directly employed labour corresponding to qth earning class, in unit operation of jth activity. ($q = 1,\ldots w$, $j = 1,\ldots,n$).

Then

DX should give the total requirement of <u>directly employed labour</u> corresponding to all the w earning classes separately to operate the production activities at a level of X.

4.5.2.2 <u>Indirect Labour</u>: For producing the 'm' inputs that correspond to 'A' matrix, the labour required is not taken into account in 'B' matrix. This becomes indirect-labour for construction. We have a matrix S (of order wxm) whose elements "s_{qi}"s give the following information:

s_{qi} = requirement of qth earning class labour to produce unit amount of ith intermediate input ($q = 1,\ldots,w$, $i = 1,\ldots,m$)

Now SA gives the required amount of labour of all the w earning classes separately for unit operation of each activity. SA is of the order (wxm). Let

$$SA = N \tag{4}$$

Then NX should give the total requirement of <u>indirectly employed labour</u> corresponding to all the w earning classes separately to operate the production activities at a level of X.

4.5.2.3 Direct and Indirect Labour

Now,

$(D+N)X$ should give the total requirement of direct and indirect employment corresponding to all the w earning classes separately for operating the production activities at a level of X. We specify a minimum level of employment for each earning class, that this construction programme should absorb. These levels are prescribed by a Vector $\bar{E}$. Then

$$(D+N)X \geq \bar{E} \tag{5}$$

becomes the set of constraints on the employment levels for each earning class.

4.5.3 Total employment constraints:

It must be obvious that the total employment (aggregated, not earning class wise) generated by any activity j per its unit operation is the following:

Total employment = direct employment + indirect employment

i.e. $$l_j = \sum_q d_{qj} + \sum_q n_{qj} \tag{6}$$

where d_{qj} and n_{qj} are the elements of D and N matrices respectively. Let

$$L = \left[l_1, l_2, \ldots, l_j \ldots, l_n\right]$$

Then $$LX \geqq \bar{E}_t \tag{7}$$

becomes the fourth set of constraints (in fact this is a single constraint) in this model, where $\bar{E}_t$ is the stipulated minimum amount of total employment to be generated by this programme.

4.5.4 Output constraints: With the available production alternatives, we are to build a specified house. This implies a certain amount of task at each and every stage of its construction. These task levels can be incorporated into a vector called $\bar{\bar{Y}}$.

$\bar{\bar{Y}} = \left(Y_1, Y_2, \ldots, Y_k\right)'$ where Y_k = output required in kth stage of construction.

We require a matrix Q of output coefficients to be written, corresponding to the production alternatives. The elements q_{jk} of Q have the following meaning:

q_{jk} = output coefficient of jth activity in kth stage.

Then

$$QX = \bar{\bar{Y}} \tag{8}$$

becomes the fifth set of constraints in this model.

4.5.5 Internal or Technical constraints: The nature of building construction is such that, one cannot build a house by picking up at random any one technique or activity at a time from each stage. Some of the activities in one stage may not be able to be coupled with some of the activities in another stage. In a multistage production programme some of the stages might be independent in the sense, selection and levels of the techniques in these stages have nothing to do with the selection and levels of the techniques in other stages; but some of the stages might be such that the selection and levels of the techniques in these stages cannot be done independently.

In the latter case, one has to account for the interdependences and internal balances in production. In order to take care of such internal constraints that are dictated by the technical relations, a matrix P is written. Corresponding engineering calculations involved in working out the allowable activity-combinations, determine the values of the elements p_{ij}"s of P. Formally these constraints can be written as

$$PX \geqq 0 \tag{9}$$

Some explanation is necessary here to understand how 'p_{ij}"s are derived and what they stand for. Suppose X_i and X_j are two activities belonging to two different stages i and j respectively. Say stage i corresponds to foundation and stage j to superstructure wall. If a wall built by using technique X_j can be constructed only on a foundation built by using technique X_i, a constraint to this effect should be introduced into the model. This constraint can be worked out as follows:

Let

x_j = superstructure wall work in cubic metres, built by using technique X_j;

and x_i = foundation work in cubic metres, buit by using technique X_i.

As the dimensional details of both wall and foundation are known (by means of engineering details given in Appendix A), we can calculat the lengths for which x_j and x_i are built, by multiplying their levels with proper constant*

Let us say $K_i x_i$ = Length for which the foundation is built by using technique X_i

$K_j x_j$ = Length for which the wall is built by technique X_j

If technique X_j can go only with X_i this implies that $K_i x_i$ should at least be as long as $K_j x_j$. (i.e.)

$$K_i x_i - K_j x_j \geqq 0$$

or

$$x_i - \frac{K_j}{K_i} x_j \geqq 0 \qquad (A)$$

The coefficients of x_i and x_j (1 and $\frac{K_j}{K_i}$ respectively) become the elements 'p_{ij}'s of P.

The constraints of this type in building construction explain also the necessity of an integrated systems approach, as we have adopted here, in solving this problem. For instance, if the problem is solved in a partial approach, analysing different stages of the construction separately, it is possible to find that x_j is the optimal technique among the alternatives in stage j and x_i. but not x_i is the optimal one among the alternatives in stage i. Then constraint (A) is not satisfied. Hence, it is necessary to analyse both the stages i and j simultaneously In building construction such interdependences exist from foundation bed onwards upto the material used in

---

* For instance if the wall is 9" wide and 12' high, then x_j cubic feet of wall work amounts to $x_j/((3/4)' x 12') = x_j/9$ feet long wall. Here $K_j = 1/9$.

superstructure walls and sometimes even upto whether or not plastering is required at all.

4.5.6 <u>Nonnegativity constraints</u>: These constraints restrict the choice variables from assuming negative values. These are the following:

$$T \geqq 0$$
$$X \geqq 0 \tag{10}$$

4.5.7 <u>Objective function:</u> Our objective is to select the levels of different technical alternatives, so that the cost is the least possible. Here, the cost is evaluated in terms of money consisting of cost of the k primary factors described in the T vector and all the remaining costs involved in the operation of the technical alternatives X_j, $j = 1,\ldots,n$ of the X vector.

The objective coefficients (C_j) of the productive activities (X_j) include transport costs involved through intermediate inputs , the direct and indirect labour costs and any other miscellaneous costs. The objective is thus to

$$\text{minimize} \quad C \begin{bmatrix} T \\ X \end{bmatrix} = \sum_{i=1}^{k} C_i t_i + \sum_{i=k+1}^{n} C_i X_i$$

where C is the order $1x(k+n)$

T is the order $kx1$ as $(t_1,\ldots,t_k) = T'$ that appeared in (3)

X is the order $nx1$ as $(X_1,\ldots,X_n) = X'$ as defined previously

4.5.8 Summary of Model and its Solution:

In a nutshell, the model is as written below:

Objective Function Minimize $C \begin{bmatrix} T \\ X \end{bmatrix}$

Subject to:

Constraints:

(i)	Resource balance equations	$IT - BAX$	$= 0$
(ii)	Employment Constraints corresponding to income-classes	$(D+N)X$	$\geqq \bar{E}$
(iii)	Total Employment Constraints	LX	$\geqq E_t$
(iv)	Output Constraints	QX	$= \bar{Y}$
(v)	Internal or Technical Constraints	PX	$\geqq 0$
(vi)	Nonnegativity Constraints	T, X	$\geqq 0$

The solution worked out from the above model will give the following:

(1) the optimal amounts of "t_i"s i.e. capital, fuel and material resources that make the construction programme the least cost one at a given price structure;

(2) as a part of the solution, the optimal levels of various "X_i"s i.e. the production techniques available as alternatives in building construction and also

(3) the levels of employment of labour force corresponding to different income-groups

4.5.9 Comments on the above Model: (a) capital in the model appears only through the B-matrix. This is the one required in the production of intermediate inputs like cement, bricks, steel etc. This is because of the assumption that no direct capital is involved in the construction activities.

(b) Usually, labour is treated as homogeneous. This corresponds to our total-employment constraint. But to assess the impact on income distribution in the society, the structure of the employment is to be observed. In this model, six different income-groups are identified and separate constraints are maintained for each of them. Including the constraint on total employment, there are in all seven constraints on employment. Given such constraints at a disaggregated level, the following type of problem can be analysed.

Increasing total employment may sometimes mean increasing employment of skilled labour force belonging to higher income strata of the society. Undesirable effects on the income distribution aspects of the society are obvious in this case. In such situations a minimum level of unskilled labour-employment also can be insisted, by placing separate constraints for different incomegroups.

(c) The model converts every intermediate input into primary resources required on its own production. Two explanations for such conversion are the following:

(i) The flexibility involved in defining the output based on its functional utility, raised the necessity of such a conversion (see page 485). The variation in the ntermediate inputs from techniques to technique in producing he output defined such a way, causes variation in other rimary material resources, other than capital and labour. o explore the substitution possibilities between these aterial resources also, they had to be accounted for n detail.

(ii) Though this model is confined only to the onstruction sector, a linkage to the other sectors of the conomy is provided through the activities of production of ntermediate inputs. As mentioned in Chapter I earlier this s a step towards general equilibrirum analysis from partial quilibirum analysis within the scope of our study.

4.6 Model for Road Construction: The only differences between the models for building construction and road construction are the following:

(a) The stages involved in road construction are different from these in the building construction explained under 4.5.1.

(b) Direct capital involved in the operation of the activities in road-construction, unlike in building construction, cannot be neglected.

The modifications brought into the model for road construction are discussed below:

(a) Stages of the Road construction: Following are the different stages involved in different ways of road construction:

Stage 1 : Earth excavation

Stage 2 : Preparation of subgrade

Stage 3 : Soling work

Stage 4 : Subbase work

Stage 5 : Wearing surface

Stage 6 : Premix Carpet

Stage 7 : Sealing coat

Stage 8 : Wearing coat.

These stages are derived from the work involved in onstructing different types of roads for serving a given raffic density. This means that different types of roads ight require different stages. Hence for building any articular type of road, not all the above stages are ecessary. For example, to build a concrete road stages 3,5,6 nd 7 are not necessary.

All the above eight stages imply five different ypes of roads. For each type of road several alternative echniques are accounted. These activities form the X vector or road construction.

(b) Direct capital in road construction: Each ctivity (X_j) in the X-vector requires some amount of direct apital. (These details are given in the data provided at e end. The cost fixed capital is accounted by working out e economic rental rates for such capital equipment based the given interest rate.

Let

$d_{cap.j}$ = Rental on fixed direct capital required for unit operation of X_j

Now consider B matrix. We know that

b_{pi} = requirement of pth primary factor to produce unit output of ith intermediate input ($p=1,\ldots,k$ and $i = 1,\ldots.m$)

Similarly from A matrix we know that

a_{ij} = requirement of ith input to produce unit output of jth activity (i.e. unit operation of X_j)

Then $\sum_i (b_{pi})(a_{ij})$ = requirement of pth primary factor to produce necessary inputs required for unit operation of X_j

Let p refer to rental on capital. Then

$\sum_i (b_{pi})(a_{ij})$ = Rental on the capital required to produce necessary inputs required for unit operation of X_j i.e. total indirect capital required for unit operation of X_j.

Now

$(d_{cap.j})+\sum_i (b_{pi})(a_{ij})$ = Rental on total direct and indirect fixed capital required for unit operation of X_j.

Then the total rental t_p on direct and indirect fixed capital required to run the production activities at a level of X is given by

$$t_p - \sum_j \left[d_{cap.j} + \sum_{i=1}^{m} (b_{pi})(a_{ij}) \right] X_j = 0$$

As far as comments on the above model on road construction are concerned, all those except 4.5.9(a) described under building construction hold true here also.

Chapter V

STATISTICAL BASIS FOR THE MODEL

5.1 Introduction

The previous chapter described in detail the analytical structure of the linear programming model formulated for identifying the appropriate technology for building and road construction. This chapter is devoted to an evaluation of the empirical basis for all the data and figures required for the model. Following pages explain in detail how data were collected from various sources and how they were processed.

5.2 Data for 'A' matrix

Most of the data used in this project have been collected from the documents called "Analysis of Rates for Delhi" Vols. I to IV published by the Central Public Works Department (CPWD), Ministry of Works and Housing, New Delhi. These documents give data mainly about materials and mandays required for unit operation of various techniques. These techniques have been classified into different sections like earthwork, brickwork, stonework, concretework, reinforced cement concrete work, flooring, roofing, plastering, finishing and road work etc. The material data corresponding to these techniques form the intermediate inputs (cement, bricks, lime, steel etc.) described in 'A' matrix. These data conform to engineering specifications like waterement ratio, proportions by volume or weight, bulkage factor tc., and arithmatic calculations like number of standard ize bricks or stones or blocks per cubic metre. For example, he amount of cement needed for a cubic metre of 1:2:4 cement oncrete is a constant which does not change with respect to he agent who supplied the value of this constant. Hence ny differences in these data from one source to another are arginal and no special importance needs to be given for the ethod of collection of the data. These data are available oth in physical and monetary units in these documents. onetary units are based on 1972 prices. It is not explained nywhere in these volumes, how the price data have been ollected. However, only the data in physical units have een used in the A-matrix of the model.

The rows of the A matrix correspond to the following inter- iate inputs: cement, bricks, coarse sand, finesand, stone aggregate, nslaked lime, surkhi, quarry stone, through and bond stones, teel, sandstone, diesel, and bitumen. The columns corres- ond to the technical alternatives for all the stages of he construction (building or road). This set is the hoice set of alternatives from which proper techniques ave to be selected. The elements "a_{ij}" s of the A-matrix ply the following:

a_{ij} = amount of ith intermediate input required per unit operation of jth activity.

Lists, Option list a and Option list b, consisting of all these alternatives in the construction of a building and a road separately are provided below. 'A' matrices for building and road construction are presented at the end of this volume.

Option List-a

'Option list-a' consists of the productive activities i.e. technical alternatives available at various stages of the construction of a building:

Stage : Foundation bed for Load bearing Walls:

1:4:8 Cement concrete foundation bed : 148 FBL
1:3:6 Cement concrete foundation bed : 136 FBL
1:2:4 Cement concrete foundation bed : 124 FBL

Stage : Foundation bed for Partition Walls

1:4:8 Cement concrete foundation bed : 148 FBP
1:3:6 Cement concrete foundation bed : 136 FBP
1:2:4 Cement concrete foundation bed : 124 FBP

Stage: Super Structure in Load bearing and Partition Walls:

1:3 Cement mortar brick wall : 13 CBLW*, 13 CBLP*
1:2 Cement mortar brick wall : 12 CBLW , 12 CBLP
1:4 Cement mortar brick wall : 14 CBLW , 14 CBLP
1:6 Cement mortar brick wall : 16 CBLW , 16 CBLP
1:1:6 Cement Lime mortar brick wall : 116 BLW, 116 BLP
1:2:9 Cement Lime mortar brick wall : 129 BLW, 129 BLP
1:1:8 Cement Lime mortar brick wall : 118 BLW, 118 BLP
1:1:3 Cement Lime mortar brick wall : 113 BLW, 113 BLP
1:1:1 Lime Surkhi sand mortar brick wall: 111 BLW, 111 BLP
1:2 Lime Surkhi mortar brick wall : 12 LBLW, 12 LBLP

---

* LW denotes Load bearing walls, LP denotes Partition walls.

1:4 Cement mortar coursed stone masonry : 14 CCLW
1:6 Cement mortar coursed stone masonry : 16 CCLW
1:1:1 Lime Surkhi sand coursed stone masonry : 111 CLW
1:1:8 Cement Lime mortar coursed stone masonry : 118 CLW
1:4 Cement mortar random Stone masonry : 14 CRLW
1:6 Cement mortar random stone masonry : 16 CRLW
1:1:1 Lime Surkhi sand random stone masonry : 111 RLW
1:1:8 Cement Lime mortar random stone masonry : 118RLW
Precast block wall : PCHBLW, PCHBLP

Stage: Foundation work under super structure

1:3 Cement mortar brick foundation : 13 CBFL*, 13CBFP*
1:2 Cement mortar brick foundation : 12 CBFL ,12CBFP
1:4 Cement mortar brick foundation : 14 CBFL ,14CBFP
1:6 Cement mortar brick foundation : 16 CBFL, 16CBFP
1:1:6 Cement Lime mortar brick foundation : 116 BFL, 116BFP
1:2;9 Cement Lime mortar brick foundation : 129 BFL, 129BFP
1:1:8 Cement Lime mortar brick foundation : 118 BFL, 118BFP
1:1:3 Cement Lime mortar brick foundation : 113 BFL, 113BFP
1:1:1 Lime Surkhi sand mortar brick foundation: 111 BFL, 111BFP
1:2 Lime Surkhi mortar brick foundation : 12 LBFL, 12LBFP
1:4 Cement mortar coursed stone foundation : 14 CCFL
1:6 Cement mortar coursed stone foundation : 16 CCFL
1:1:1 Lime Surkhi sand mortar coursed stone foundation : 111 CFL
1:1:8 Cement Lime sand mortar coursed stone foundation : 118 CFL
1:4 Cement mortar random stone foundation : 14 CRFL
1:6 Cement mortar random stone foundation : 16 CRFL
1:1:1 Lime Surkhi sand mortar random stone foundation : 111 RFL

---

*FL indicates foundation for Load bearing walls, FP that for partition walls.

1:1:8 Cement lime sand mortar random stone foundation : 118 RFL

Precast block foundation :PCHBFL, PCHBFP

Stage : Roof Work

1:2:4 Cement concrete roof of balanced design : 124 BRF

$1:1\frac{1}{2}:3$ Cement concrete roof of balanced design : 11.53 R

1:1:2 Cement concrete roof of balanced design : 112 BRF

1:2:4 Cement concrete roof of over reinforced design: 124 ORF

1:2:4 Cement concrete roof of under reinforced design: 124 URF

Reinforced brick roof : RBROOF

1:3:6 Cement concrete roof of balanced design : 136 BRF

Stage : Flooring Work

40 mm thick 1:2:4 cement concrete flooring : 124 FLG

Brick flooring in 1:4 cement mortar : 14 BFLG

Brick flooring in 1:6 cement mortar : 16 BFLG

Rough chiselled sandstone flooring in 1:5 cement mortar : 15 RFLG

Fine dressed sandstone flooring in 1:5 cement mortar : 15 FFLG

Stage : External and Internal Plastering

12 mm thick plastering in 1:6 cement mortar : 16 CPLI*
16 CPLE*

12 mm thick plastering in 1:1:7 cement lime mortar : 117 PLI
: 117 PLE

12 mm thick plastering in 1:2:9 cement lime mortar : 129 PLI
129 PLE

12 mm thick plastering 1:2 lime surkhi mortar : 12 LPLI

12 mm thick plastering 1:1:1 lime surkhi sand mortar : 111 PLI

Option List-b

'Option list-b' consists of the productive activities i.e. technical alternatives, available for the road construction. They are as follows:

---

*I denotes Internal, E denotes External plastering

Capital intensive excavation technique : CAPEXC
Labour intensive excavation technique : LABEXC
Preparation of subgrade : PREPSG
Soling work technique for asphaltic road : SOLING
Water-bound macadam work technique for asphaltic road : WBMCDM
Premix-carpet work technique for asphaltic road : PRCRPT
Sealing coat work technique for asphaltic road: SLCOAT
Cement concrete subbase work technique : 148 SBC
Lime concrete subbase work technique :111 SBC,* 111 SBP
Water bound macadam subbase work technique WBMSBC
Puzzolana concrete wearing coat technique PUZWCT
Cement concrete wearing coat technique 124 WCT

5.3 Data for 'B' Matrix

Matrix B consists of the information related to conversion of intermediate inputs into primary resources like capital, fuel etc. required in the production of the intermediate inputs. Columns of B matrix correspond to the rows of 'A' matrix exactly in that order. B matrix has rows corresponding to the following primary resources:

capital (Rs.)
electricity (kwh)
coal (tonnes)
limestone (tonnes)
quarrystone (cu.m.)
bitumen (tonnes)
gypsum (tonnes)
clay (tonnes)
water (tonnes)
ironore (tonnes)
sandstone ($q.m)
moorum (cu.m.)
manganeseore (tonnes)
dolomite (tonnes)
coarse sand (cu.m.)
finesand (cu.m.)
diesel (litres)
miscellaneous expenditure (Rs.)

---

* 111 SBC is intended for 124 WCT whereas 111 SBP is for PUZWCT.

The elements "b_{ij}" s of B matrix mean the following:

b_{ij} = amount of ith primary resource required for producing a unit amount of jth intermediate input.

The elements "$(b\ a)_{ij}$" s of "(BA)" matrix give the following information:

$(b\ a)_{ij}$ = amount of the ith primary resource required directly and in the production of the intermediate inputs required for unit operation of the jth activity.

Data for "B"-matrix were collected from several text books on engineering chemistry, and handbooks on civil engineering. Table 5.1 provides the details regarding the sources of information.

Table 5.1

Item	Unit	Source of Information
Cement	tonnes	"Outlines of Chemiical Technology" by Gopala Rao M and Marshall Stillig.
Bricks	thousand	"Practical Civil Engineers Handbook" by P.N.Khanna
Stone aggregate	cu.m.	"Analysis of Rates "by CPWD.
Unslaked lime	quintal	"Working of the experimental improved lime kiln" by Khadi and Village Industries Commission
Surkhi	cu.m.	National Buildings Organization
Quarrystone	cu.m.	"Analysis of Rates" by CPWD
Through and Bondstones	No.	"Analysis of Rates" by CPWD
Steel	Kg.	"Outlines of Chemical Technology" by Gopala Rao M and Marshal Stillig
Sandstone	sq.m.	"Analysis of Rates" by CPWD.

5.4 Data on Direct Labour

Direct Labour details in the form of mandays required per unit operation of various techniques were obtained, again from Analysis of Rates vol. I to IV that have earlier been referred to. These details have been given occupationwise i.e. I class masons, II class masons, blacksmiths, beldars, bhishti and so on. Corresponding wage rates for 1972 have also been provided. The occupation-classification given by 'Analysis of Rates for Delhi' have been converted into wage group classification for every technique included in the 'A'-matrix. Thus the 'D'-matrix is derived based on the information on wage rates. The following is the wage structure given by 'Analysis of Rates for Delhi'

	Rs./day
I class mason (Brickwork)	8.80
II class mason (Brickwork)	7.00
Blacksmith I class	8.80
Bhishti	4.70
Beldar	3.50
Coolie	3.50
Mate	4.70
Bandhani	4.70
Mistry	8.80
Mason for plain stonework	7.00
Mason for ornamental stone work	8.80
I class stone cutter	8.80
II class stone cutter	7.00

Depending upon the above wage structure the following earning groups have been identified:

DL 1	0 to 4 Rs./day
DL 2	4 to 5 Rs./day
DL 3	5 to 6 Rs./day
DL 4	6 to 8 Rs./day
DL 5	8 to 10 Rs./day
DL 6	≥ 10 Rs./day

One point is to be noticed here. Obviously, we require some empirical observations on the labour required for unit operation of a technique. It is only the vast experience which provides these data. Since the Central Public Works Department is one of the large concerns undertaking both heavy and light construction works, I relied upon the data supplied in the Analysis of Rates by CPWD regarding the labour inputs.

5.5 Data on Indirect Labour

For the information required for S matrix, there is not a unique source from where one could get all the details required. Several sources of information were tapped. Data on labour component in cement production were collected from an unpublished study done at Indian Statistical Institute, New Delhi by Kirit S. Parikh and M.R. Saluja[1] on industrial wage structure. Labour details for brick production are synthesised from an article of A.V.R. Rao[2] of National Building Organization on brick-making. The following documents

---

[1] This study is based on the data given in the 2nd Occupational Wage Survey of India.

[2] A.V.R. Rao (1970).

also have been particularly useful in obtaining the details on labour components involved in the production of other intermediate inputs:

(1) Annual Survey of Industries

(2) Practical Civil Engineers Handbook by P.N.Khanna

(3) Men or Machines (A Philippenes Case Study of Labour Capital Substitution in Road Construction) by Dipak Lal

(4) Working of the Experimental Improved Lime kiln by Khadi and Village Industries Commission.

The wage (per day)-groups maintained for this indirect labour are same as those for direct labour, i.e. 0 to 4 Rs., 4 to 5 Rs., 5 to 6 Rs., 6 to 8 Rs., 8 to 10 Rs., and greater than 10 Rs.

5.6 Information on "Precast" Techniques

Information on precast techniques is collected from the various publications of the Concrete Association of India. Data for these techniques are not available in CPWD publication. Data in these publications are available in the same form as that in Analysis of Rates by CPWD. Hence, no more explanation regarding data-processing is needed. The following booklets of the Concrete Association of India have been consulted for the needed technical information:

(1) Elementary Handbook of Concrete House Construction
(2) Low Cost Concrete Houses
(3) Precast Concrete Houses
(4) Low-cost Soil Cement Houses

5.7 Data for Calculations of Output and Technical Constraints

5.7.1 Building Construction. Output, as explained in the first chapter, is defined to be a house, serving middle Income groups. Its plinth area is 450 sq.ft.(apr). Construction of this house is split into several stages. Each stage is designed according to the technical requirements specified y National Building code and Building-Bye-Laws of Indian Standards Institution, with respect to all the techniques vailable in that stage. (See the Option list -a in this hapter). These civil engineering calculations determine the utput coefficients in Q matrix and the task levels in $\overline{Y}$. Handbooks published by National Buildings Organization, by .N.Khanna, Gurucharan Singh etc. and specifications suggested y Indian Standards Institution and other text books on uilding construction, concrete structures, and strength of aterials have been consulted at this level. Detailed alculations involved in the design can be seen in the ppendix A. Drawings of the building in plan & front elevaion ~~and~~ ~~cross~~ ~~section~~ are shown in plates 1 & 2.

One can produce this output by employing any of the echniques described in the 'Option list -a' for the above tages of the construction. Altogether eighty six alternaives are identified for all the stages taken together. able (1-a) in Chapter I explained the basis of formulating he option list for this exercise. Common building techniques are all included in the model. viz., at the superstructure level, choice set comprises of brick, stone (random rubble and coarsed rubble) and precast block masonry techniques in different mortars like cement, cement-lime, lime-surkhi mortars of varying proportions. Similarly at roof level, reinforced-cement-concrete roofs of different concretes and of different designs* like balanced, over andunder reinforced cases are considered. At flooring level, concrete flooring, brick flooring, rough chiselled sandstone flooring and finely dressed sandstone flooring in different mortars have been included. For plastering, cement-plastering, cement-lime plastering and lime-surkhi plastering have been considered depending upon whether it is external or internal plastering.

The nature of building construction is such that a house cannot be built by picking up at random any one technique or activity from each stage. It implies that all the activities in one stage cannot be coupled with all the activities in another stage. For example, a stone superstructure is not built on a brick foundation. However, a brick superstructure is allowed to be built over a stone foundation. A brick superstructure is not in general built over a precast

---

* Thickness of a roof depends upon the amount of steel reinforced into it. The usual criterion of deciding this thickness is to make bending moment due to load on the roof equal to the resisting moment developed by it. This is known as "balanced" design. Though these two moments are not equal, a safe roof can still be built by adjusting the steel and concrete amounts. These two 'unequal" cases are known as under reinforced and over reinforced designs. These designs explore the substitution possibilities between steel and concrete.

block foundation. To take care of such internal engineering constraints dictated by the possible technical combinations, a matrix P is written. The coefficients "P_{ij}"s of P restrict the solution to only feasible technical combinations. The civil engineering calculations involved in working out such allowable activity combinations determine the values of "p_{ij}"s. Chapter IV and Appendix A can be referred for the details on how "p_{ij}" s are derived. Again, the handbooks by National Buildings Organization (N.B.O.) and Indian Standards Institution (I.S.I.) and others have been consulted for these calculations.

Fortunately the nature of fixed proportions between the activities that can be combined could be sufficient in working out these technical constraints. The fact that the length of the superstructure wall is equal to the length of the foundation (which is a linear relation) below it, is explored here.

5.7.2 Road Construction: As reported earlier, output in this case is defined to be a National Highway of one kilometre length with the following specifications:

formation width[1] = 12 metres
carriage way width[2] = 7 metres
wheel load = 12000 lb.

---

[1] Formation width is the finished top width of earth work in fill/cut for receiving the road structure.

[2] Carriage way is the portion of the roadway designed and constructed for vehicular traffic.

Following are the different stages involved in different ways of road construction:

Stage 1	Earth excavation
Stage 2	Preparation of subgrade
Stage 3	Soling work
Stage 4	Subbase work
Stage 5	Wearing surface or waterbound macadam work
Stage 6	Premix carpet
Stage 7	Sealing coat
Stage 8	Wearing coat

Each stage is designed according to the technical specifications required for a National Highway. These calculations determine the output coefficients in Q matrix and the task levels $\bar{Y}$. The following works have been very useful in this connection:

Practical Civil Engineers Handbook by P.N.Khanna

Handbook on Civil Engineering by Gurucharan Singh

Economics of Highway Pavement Design by Bh.Subbaraju and M.P.Dhir

Appendix A gives the details on the calculations involved "Option-list-b' gives an account of the thirteen different activities identified for road construction. These activities are included in the model on the basis of the five different types of roads mentioned in table (1-b) in Chapter I.

The nature of road construction is such that for building the road, not all the above mentioned stages are required. For example, for building a cement concrete road stages 6 and 7 are not necessary. Similarly for building a bituminous road stages 4 and 8 are not necessary. To take care of such internal engineering constraints dictated by the possible technical combinations, a matrix P is written. The coefficients "P_{ij}"s of P restrict the solution to only feasible technical combinations. Chapter IV and Appendix A can be referred for the details on how "P_{ij}"s of P are derived.

5.8 Data and Calculations for Rental Values on Fixed Capital

5.8.1 Building Construction: It is to be noted that we have assumed that for all the activities in building construction direct capital is negligible. So only indirect capital remains to be calculated for each activity. This is the capital required in producing the intermediate inputs. One of the rows of the B matrix corresponds to capital. In calculating the rental values on capital per unit of each of these inputs , the capital-output coefficients given by M.R.Saluja[1] have been used mainly. For bricks, the information given by A.V.R.Rao[2] on the corresponding initial investment is utilized. From this, rental value on capital involved in the production of surkhi is deduced. Surkhi is

---

1/ M.R.Saluja (1971)

2/ A.V.R.Rao (1970).

powdered burnt clay or powder of over-burnt bricks. These rental values are calculated on the one horseshay assumption that capital provides the same services over its life of n years. Given n and the interest rate i, the annual rental R is given by the following formula.

$$P = R \frac{1-(1+i)^{-n}}{i}$$

where P = present value (cost) of the capital

R = the annual rental

i = the rate of interest desired

n = the number of years

However, these calculations require assumptions about interest rate (i) and longevity of capital (n). For cement and steel n is assumed to be 20 years, for bricks 6 years, for lime 15 years and for the rest 10 years. Rental values are obtained for i = 5, 10, 15, 20, and 25 percent.

Rental values corresponding to an interest rate of 20 percent are considered for the base (initial) solution. Those corresponding to other interest rates are used for testing the sensitivity of the base solution obtained.

5.8.2 Road Construction: Much of the information on the direct fixed capital required in the road construction is provided by 'Analysis of Rates for Delhi" by . . . C.P.W.D. Details corresponding to the capital-intensive and labour-intensive techniques of excavation are borrowed from "Men or Machines": A Philippenes Case Study of Labour-Capital Substitution in Road Construction" by Deepak Lal. These details were taken in terms of physical coefficients and Indian prices were applied to suit the Indian conditions. For indirect capital, the data sources are exactly the same as under the case of buidling construction.

Procedure of calculation of the rental values for direct and indirect capital also is the same as under the case of building construction. The following table gives the details of the life-time (n) assumed on various capital equipment items:

Bulldozer (90 h.p.)	= 6 years
Concrete Mixer	= 15 years
Coal-tar boiler	= 10 years
Road roller	= 10 years
Hot-mix Plant	= 10 years
Wheel barrow	= 4 years
Pick axe	= 3 years
Shovel	= 1 year
Fork	= 1 year

Rental values are obtained for i = 5, 10, 15, 20 and 25 percent (interest rate). The base or initial solution corresponds to an interest rate of 20 percent. Sensitivity analysis with respect to other interest rates is carried out.

5.9 Objective Function Coefficients

Cost coefficients in the objective function are based on 1972 prices. We have already seen that the objective function has two types of variables (or activities): (a) production activities (X_j) and (b) resource activities (t_j).

(a) Production activities:

Cost per unit operation of each activity =

Direct labour costs+Indirect labour costs
+ Transport costs + Shuttering costs if any
+ Miscellaneous costs if any.

Since complete information about the direct and indirect labour components involved per unit operation of each activity (see D and N matrices) and also the corresponding wage structure are known, the direct and indirect labour costs for each activity could be calculated easily.

Transport costs are involved in bringing intermediate inputs to the site of construction. Data on these costs are provided by Analysis of Rates, C.P.W.D. These rates correspond to transport by mechanized means for a distance of 5 km. Same rates are used for calculating transporting costs of precast techniques also, because the Concrete Association of India did not supply 1972 transport costs for these techniques.

Shuttering costs are supplied by Analysis of Rates. These costs are incurred for reinforced cement concrete works only.

(b) Resource activities: For resources other than capital, (i.e., electricity, coal, ores, sand etc.) their unit costs i.e. Rs./unit at 1972 prices, are taken to be the cost coefficients. The following documents were consulted for obtaining this information:

(1) Mineral Statistics of India, 1973

(2) Analysis of Rates for Delhi 1972 (CPWD)

(3) Schedule of Rates for Delhi 1972 (CPWD)

(4) Working of the experimental improved lime kiln by Khadi and Village Industries Commission.

We conclude this chapter on the statistical basis of the data required for the model, by mentioning that wherever the figures were required to be inflated to 1972 values from any previous year, the following two documents were consulted:

(a) Index Numbers of Wholesale Prices published by Central Statistical Organization. (C.S.O.)

(b) Economic Survey, published by Govt. of India.

Chapter VI

THE NUMERICAL RESULTS

This chapter reports and interprets the numerical results obtained after solving the models described in chapter IV for indentifying the appropriate set of techniques of production in building and road construction.[1] This chapter is divided into Parts I and II. The first part consists of sections 6.1 to 6.5 which contains the results and their analyses for building construction. The second part deals with road construction and consists of sections 6.5 to 6.10.

Part I

6.1 Appropriate Technology for Building Construction

The house that has been selected for this project work, has been already described in Chapter I. Its 'plan' & 'front-elevation' ~~and~~ '~~cross-section~~' details are presented in plates 1 to 2. Its engineering-design details are given in Appendix A. The problem on building construction had the following number of constraints:

Resource-balance equations	14
Employment constraints corresponding to earning-groups	6
Total Employment constraint	1
Technical constraints	5
Output constraints	8
	34

---

[1] For solving these problems, IMB 360 and IBM 1620 computers were used.

and the following number of structural (other than slack) columns:

Resource activities 14+1
Production activities 86
100+1 = 101.

Section 6.2 deals with the discussion of the base (initial) solution. Section 6.3 deals with the discussion of the sensitivity analysis (parametric programming) and related issues.

6.2 The Base Solution

For obtaining the base solution, we assumed the interest rate for rental-value on the fixed capital to be 20 percent. The output (i.e. a house) is to be produced with a non-negative level of the total employment. The employment-levels of the different earning-groups also are required to be at a non-negative level. After solving the model initially, the base solution obtained is the following:

Table: (6.2.1-a) The Resource and Production Activities of the Base Solution

Objective Function (minimized cost) (O)= Rs.4882.57

Resource activities

Capital Rental (K)*	= 689.69 Rs.	Electricity =	= 313.345 Kwh
Coal	= 5.483 tons	Limestone	= 9.596 tons
Gypsum	= 0.156 tons	Clay	= 69.352 tons
Water	= 11.75 tons	Ironore	= 0.43 tons
Manganeseore	= 0.029 tons	Dolomite	= 0.020 tons
Coarsesand	= 12.56 cu.m.	Quarrystone	= 16.943 cu.m.
Fine sand	= 2.675 cu.m.	Miscellaneous	=931.292 Rs.

---

* Throughout this project by capital-cost we mean the cost of rental on fixed capital.

Production activities

148 FBL = 2.65493 cu.m.
111 BFL = 2.8671 cu.m.
111 BLW = 14.02 cu.m.
136 BRF = 41.82 sq.m.
111 PLI = 16.61 sq.m.x10^2

148 FBP = 5.91191 cu.m.
111 BFP = 1.5484 cu.m.
111 BLP = 7.30 cu.m.
124 FLG = 41.82 sq.m.
16 CPLE = 10.03x10^2 sq.m.

The plinth area of the house is 450 square feet. Then, the value of the objective function implies (4882.57/450) 10.85 Rs. per square foot[*], as an index for the cost of construction at 1972 prices. This cost includes the capital cost, wage bill and materials costs. Capital rental cost is 689.69 Rs. which forms 14 percent of the total cost. The ratio of the capital rental to output is 0.141255. The wage bill came to Rs. 1696.37 which forms 34.74 percent of the total cost. This implies that materials amount to 51.13 percent of the total cost. In other words, while the materials amount to more than half and wage bill amounts to more than one-third of the total cost of construction, capital rental cost, which is again only the indirect rental costs being the rental for manufacturing the major inputs, amounts to a relatively insignificant part of it.

Let us take-up the production activities:

(i) 148 FBL, 148 FBP (1 cement:4 coarse sand: 8 stone aggregate) cement concrete work is suggested for

---

[*] Note that this does not include the cost of finishings.

providing and laying the foundation-bed below the foundation of both the load bearing walls and partition walls.

(ii) 111 BFL, 111 BFP (1 lime: 1 surkhi : 1 sand) lime-surkhi mortar brick work is suggested for providing the foundation and plinth for both load bearing walls and partition walls.

(iii) 111 BLW, 111 BLP (1 lime : 1 surkhi : 1 sand) lime-surkhi mortar brickwork is suggested for superstructure part of both, the load bearing walls which are 9" thick and partition walls which are $4\frac{1}{2}$" thick.

(iv) 136 BRF (1 cement : 3 coarse sand : 6 stone aggregate) reinforced cement concrete work is suggested for the roof of this building. This corresponds to a "balanced" design.

(v) For flooring 124 FLG (1 cement : 2 coarse sand: 4 stone aggregate) plain cement concrete work of 40 mm thick and finished with a floating coat of neat cement is suggested.

(vi) For internal plastering 111PLI (1 lime-putty : 1 surkhi : 1 fine sand) lime-surkhi plastering of 12 mm thick is found to be optimal.

(vii) For external plastering 16 CPLE (1 cement; 6 fine sand) cement plaster of 12 mm think is found to be optimal.

It is clear from the above suggested optimal technique-set, that utilization of cement is reduced to the minimum possible level. Whenever another material which can replace cement, while meeting the technical specifications and hence keeping the structural safety of the building intact, is available, such material is given preference. This is obvious from (ii), (iii) and (vi) above. For instance, at the foundation and superstructure level, it is generally observed that house builders employ techniques which use more cement. Usually the techniques adopted are either brick or stone masonry in a cement mortar of a proportion varying between 1:3 to 1:6 (cement : sand). Our solution suggests brick masonry in a lime-surkhi mortar of 1:1:1 (lime:surkhi: sand) proportion. Absolutely no cement is used at all, and lime and surkhi are substituted in place of cement.

As we pointed out in Chapter III, in view of the present cement shortage, substitution of other building materials for cement is worthwhile. E.C.R. (Expert Committee Report) and R.B.C. (Report on Building Construction) suggest the use of locally available materials such as lime and surkhi, etc. for conserving cement. The interesting feature of the base solution we obtained is that it supports those arguments. It should be noticed that, even at the prevailing price of cement (i.e. a price at which there is excess demand) "lime-surkhi" is less costly. It will be a fortiori so if the price of cement is raised to reduce excess demand (see the section on alternative cement-prices in 6.3).

Let us look at the employment aspects of the base solution. It provides a total employment of 365.992 mandays and the corresponding wage bill is Rs. 1696.37. As mentioned previously, this model does not take labour to be a homogenous product. Several classes of labour according to their wages are identified separately for direct and indirect employment. The following table gives the details of the employment structure.

Table (6.2.1-b) The Levels of the Employment (earningwise) of the Base Solution

Wage-group	Direct Employment	Mandays	Indirect Employment	Mandays
0 - 4 Rs/day	DL 1	120.225	IL 1	118.195
4 - 5 Rs/day	DL 2	24 .223	IL 2	13.034
5 - 6 Rs/day	DL 3	Nil	IL 3	4.606
6 - 8 Rs/day	DL 4	40.056	IL 4	6.59
8 -10 Rs/day	DL 5	33.322	IL 5	4.487
≥10 Rs/day	DL 6	Nil	IL 6	1.254
		217.826		148.166

The table implies that housing construction can create roughly 65 to 70 percent more employment indirectly in addition to direct employment. In other words, of the total (direct and indirect together) employment that this house-construction provides, 40 percent of it is generated through indirect employment alone. This emphasises the importance of backward linkages that the construction sector has.

Next, let us look at the composition of the employment. 'DL 1' and 'IL 1' correspond to the most unskilled labour earning less than any other category of the labour force. Total employment of this class is equal to (120.225+118.195) 238.420 mandays. This comes to more than 65 percent of the total employment (238.42/365.989 = 0.6513). This implies that the most unskilled labour force (implying lowest income group) forms a major part of the total employment provided by the housing construction. It is relevant to know also whether this unskilled labour force forms a major part of both direct and indirect employments separately.

The employment of the most unskilled labour force is 120.225 mandays, out of a total of 217.826 mandays of direct employment. This is roughly 55 percent of the total (120.225/217.826 = 0.5520). It means, the most unskilled labour force forms a major part of the total direct employment.

Coming to indirect employment, the employment of the most unskilled labour force is of 118.195 mandays out of a total of 148.165 mandays of indirect employment. This comes to approximately 80 percent of the total. This is somewhat surprising at the outset. But looking at the intermediate inputs, it is easily understandable. Except for cement and steel, the other intermediate inputs involved are like bricks, lime, surkhi, stone aggregate etc. which correspond to small-scale industries. Production of these items is believed to require limited amount of skilled labour force relatively to the large amounts of unskilled labour force. This justifies the high proportion of unskilled labour force in the indirect employment also. In fact, the share of unskilled labour force in indirect employment is more than in the direct employment.

The following conclusions emerge from the above discussion:

(a) Labour costs contribute to more than one third of total cost of the housing construction.

(b) 40 percent of the total employment generated by construction is indirect.

(c) Employment provided by housing construction is predominantly of the most unskilled labour (65 percent of the total).

(d) Share of the most unskilled labour is significantly high both in direct and indirect employment separately.

(e) Materials contribute to more than half of the total cost of the construction.

(f) At 20 percent interest-rate, the capital costs constitute merely 14 percent of the total cost of the construction of the house.

(g) The techniques using lime and surkhi turn out to be cheaper than those using cement even at its prevailing price at least for single storey housing construction, (i.e. a price at which there is excess demand for cement). It will be a fortiori so if the price of cement is raised further.

6.3 Sensitivity Analysis

Section 6.2 presented and interpreted the base solution. It is important to test the sensitivity of the base solution with respect to a change in certain parameters. For example, one might want to know whether the same solution holds true when the interest rate on the capital is changed from 20 per cent to 30 percent; what will be the set of production alternatives if the total employment to be generated is somewhat more or less than what is provided by the base solution. To arrive at the changes in the optimal technique set with respect to a specific change in such parameters, parametric programming has been done. Thus the model was run with the following variations:

(1) Alternative levels of subsidies on total employment generated;

(2) Alternative levels of subsidies on the employment of the most unskilled labour;

(3) Alternative interest rates for calculating the rental values on fixed capital;

(4) Alternative prices of cement per unit (tonne) and finally;

(5) Changing the objective function to maximising the employment generated subject to a cost constraint, from minimising the total cost subject to the employment constraints of one sort or the other. In this exercise parametric variation is done with respect to the total total cost.

The variants are taken up one by one for discussion in the following pages.

6.3.1 **Sensitivity analysis with respect to total employment:** Our interest is to know the changes in the techniques, with respect to a change in the desired level of the total employment. Base solution provided an employment of 365.989 mandays. If higher levels of employment, say 400 or 500 mandays and so on are desired, what changes should be brought about in the production techniques. A prior question is whether employment can be increased at all. Our analysis proceeded in the following way:

By raising the right hand side, $\bar{E}_t$, of the total-employment constraint

$(LX \geq \bar{E}_t)$*

in our model successively to higher and higher values, it was observed that the total maximum possible employment that can be provided with the given production set, is 606.31917 mandays. Any further increase in the employment is infeasible in the sense that no combination of techniques exists that can generate the desired employment. This implies that by certain changes in the production techniques, the employment can be increased by 65.67 percent** more than what is provided by the base solution. Naturally, this will have implications on the cost aspects also. Before we explore these let us discuss another issue.

---

* Note that the base solution was obtained by maintaining $\bar{E}_t=0$, $\bar{E}=0$.

** $(606.31917)/(365.989) = 1.6567$

The model minimizes the total cost of construction at a given price structure. This is a problem usually faced by an individual: the house-builder in our model. He would not go for increasing employment (which is a social problem) if it raises his costs. Thus the employment constraint in this problem is nothing but a macro constraint creeping into a micro-analysis. However, he will be willing to adopt employment-raising techniques, provided someone else is willing to subsidise the extra cost that he will incur by the adoption of such techniques. We assume that the society as a whole, i.e. its government provides such subsidies. Now changes in the production techniques adopted are related to changes in the level of the subsidy. Mathematically speaking, the employment constraint is written as follows:

$$LX - 1.0\ S_t = 0 \qquad (1)$$

where S_t (which is a slack column) denotes the total employment generated. The objective function is changed to

$$\text{Minimize } C = C \begin{bmatrix} T \\ X \end{bmatrix} - C_{St} . S_t \qquad (2)$$

where C_{St} (the cost coefficient in the objective function corresponding to newly introduced variable S_t) denotes the subsidy given per unit of total employment. (2) implies that net cost of construction (i.e. gross cost of construction minus total subsidy) is minimised. For $C_{St}=0$ (i.e. no subsidy), solution corresponds to the base solution and net cost is equal to gross cost.

Now it is to be seen whether employment increases (i.e. production techniques differ) as C_{St} is increased from 0 to some positive value step by step. C_{St} is given successively higher values, and the corresponding changes in the set of production-techniques are observed. Table 6.3.1.1 presents the results corresponding to this exercise.

Change in the set of techniques starts from the stage of plastering (external) and extends upto the stages of load bearing walls and foundation below them, flooring and roofing. Lime plastering (129 PLE) is found to be more employment-creating than cement plastering. However, adoption of the technique of lime plastering is observed to increase the total cost of the construction compared to the base solution. To compensate this additional cost, a rate of subsidy of Re.1/- per manday of the total employment is required. Similarly the technique of brick flooring (16 BFLG) compared to the concrete flooring (124 FLG), constructing the foundation and superstructure of the load-bearing walls with coursed stone masonry in lime-surkhi mortar, the technique of over-reinforcing while reducing the thickness of the roof (124 ORF), and the technique of finely dressed stone flooring are observed to be of higher employment potential compared to the techniques corresponding to the base solution. Adoption of these techniques increase the total cost of the house-construction compared to the base

Table 6.3.1.1

Sensitivity Analysis with respect to the credit on the Total Employment (L)

Credit on total employment(Rs.) per mandays	0	1.0	9.0	13.5	26.0	31.0
Amount(gross cost of constn. = 0)Rs.	4883	4886	5443	7639	7663	7690
Amount-net (Rs.)	4883	4516	1528	-515	-8067	-11096
Capital (K) (Rs.)	690	684	690	1163	1165	1167
Labour (L) (m.day)	366	370	435	604	605	606
DL1+IL1/L (X 10^5)	65144	65370	63070	53270	53285	53300
K/O (X 10^5)	14125	13996	12681	15221	15200	15170
L/O (X 10^5)	7496	7567	7993	7905	7892	7876
Electricity (Kwh)	313	304	300	302	302	302
Coal (tonnes)(X10)	55	55	46	53	54	55
Limestone (tonnes)(X10)	96	99	112	116	116	116
Gypsum (tonnes)(X10^3)	156	152	150	151	151	151
Clay (tonnes)(X10^2)	6935	6933	4028	3002	3266	3391
Water (tonnes)(X10^2)	1175	1140	1124	1134	1134	1134
Ironore (tonnes)(X10^3)	430	430	430	1493	1493	1493
Manganeseore (tonnes)(' ')	29	29	29	102	102	102
Dolomite (tonnes)(X10^3)	20	20	20	71	71	71
Coarsesand (m^3)(X10^2)	1256	1256	1120	970	976	979
Finesand (m^3)(X10^2)	268	268	584	584	471	471
Quarrystone (m^3)(X10^2)	1694	1694	4897	4655	4655	4655
Sandstone (sq.m.)(X10^2)	0	0	0	4600	4600	4600
Miscellaneous (Rs.)	931	926	908	1199	1208	1222

Wage bill (Rs.)	1696	1709	2044	3142	4517	4541
Residual (Rs.)	3186	3177	3399	4497	3146	3150
DL1 +IL 1 (mandays)	120+118	121+121	152+122	212+110	212+111	212+111
DL2 + IL2 ('')	24+13	24+13	25+ 8	36+ 6	38+ 6	38+ 7
DL3 + IL3 ('')	0+5	0+5	0+6	0+6	0+6	0+6
DL4 + IL4 ('')	40+ 7	40+7	84+6	137+5	137+5	137+5
DL5 + IL5 ('')	33+ 5	33+5	26+4	79+10	79 +10	79+10
DL6 + IL6 ('')	0+1	0+1	0+1	0+2	0+2	0+2
Optimal Levels of the Techniques	148FBL= 2.7 148FBP= 5.9 111BFL= 2.9 111BFP= 1.6 111BLW=14.0 111BLP= 7.3 136BRF=41.8 124FLG= 4.2 111PLI=16.6 16CPLE=10.0	148FBL= 2.7 148FBP= 5.9 111BFL= 2.9 111BFP= 1.6 111BLW=14.0 111BLP= 7.3 136BRF=41.8 124FLG= 4.2 111PLI=16.6 129PLE=10.0	148FBL= 4.3 148FBP= 5.9 111CFL= 3.7 111BFP= 1.6 111CLW=18.5 111BLP= 7.3 136BRF=41.8 16BFLG= 4.2 111PLI=16.6 129PLE=10.0	148FBL= 4.3 148FBP= 5.9 111CFL= 3.7 111BFP= 1.6 111CLW=18.5 111BLP= 7.3 1240RF=41.8 15FFLG= 4.2 111PLI=16.6 129PLE=10.0	148FBL= 4.3 148FBP= 5.9 111CFL= 3.7 111BFP= 1.6 111CLW=18.5 111BLP= 7.3 1240RF=41.8 15FFLG= 4.2 12LPLI=16.6 129PLE=10.0	148FBL= 4.3 148FBP= 5.9 111CFL= 3.7 12LBFP =1.6 111CLW=18.5 12LBLP= 7.3 1240RF=41.8 15FFLG= 4.2 12LPLI=16.6 129PLE=10.0

* Tables with * contain figures which are rounded up.

solution. Different levels of subsidy required per manday of the total employment to compensate the additional cost of the construction involved in adopting such techniques of higher employment potential are tabulated in 6.3.1.1.

At a level of subsidy of Rs.31/- per manday it appears that the employment potential of the production set is fully explored. Corresponding technique-set provides a level of total employment of 605.70394 mandays as against the maximum possible employment of 606.31917 mandays.

Let us examine the changes in the total cost of construction over the range of subsidy levels. Table 6.3.1.1 gives also these details corresponding to different subsidy levels. Between Rs. 9 and 13.50, there exists a level of subsidy at which the cost of construction is exactly equal to the total subsidy given. Any increase in the level of subsidy beyond this level would mean that the total subsidy is more than the cost of construction of the house.

Consider the solutions corresponding to the rates of subsidy of Rs. 0, 1 and 9 per manday. Let us refer them as solution I, II and III respectively. Table 6.3.1.1 presents the total wage-bills corresponding to these solutions and also the corresponding "residuals" (residual = gross cost of construction - total wage bill = total cost on all the material resources including capital).

We observe that the total-employment and hence the wage-bill are increasing over the I, II and III solutions.

Now, let us suppose that the government, instead of giving subsidy on the total employment, bears the total wage-bill. This means that the cost on labour is nill for the house-builder. Then it is optimal for the house-builder to select the set of techniques that minimises simply the total cost on all the non-labour resources i.e. the residuals. Now the house-builder is free to employ as much labour as he wants (because he need not spend a paise on them and the government bears the entire wage-bill) if it saves on the non-labour resources. In this case the set of techniques corresponding to solution II becomes optimal because the residual-cost is the least here. Note that the house-builder would save Rs. 8.99/-* on the non-labour resources if he adopts solution II instead of solution I (base solution). He would not adopt solution III because, though the employment level increases it involves an increase in the cost of non-labour resources also. That means that no more substitution possibilities exist between labour and non-labour resources and in fact only a complementary-relation holds.

However, solution III is interesting in a different way. Observe the capital-output and labour-output ratios for all the solutions. They are the lowest and highest

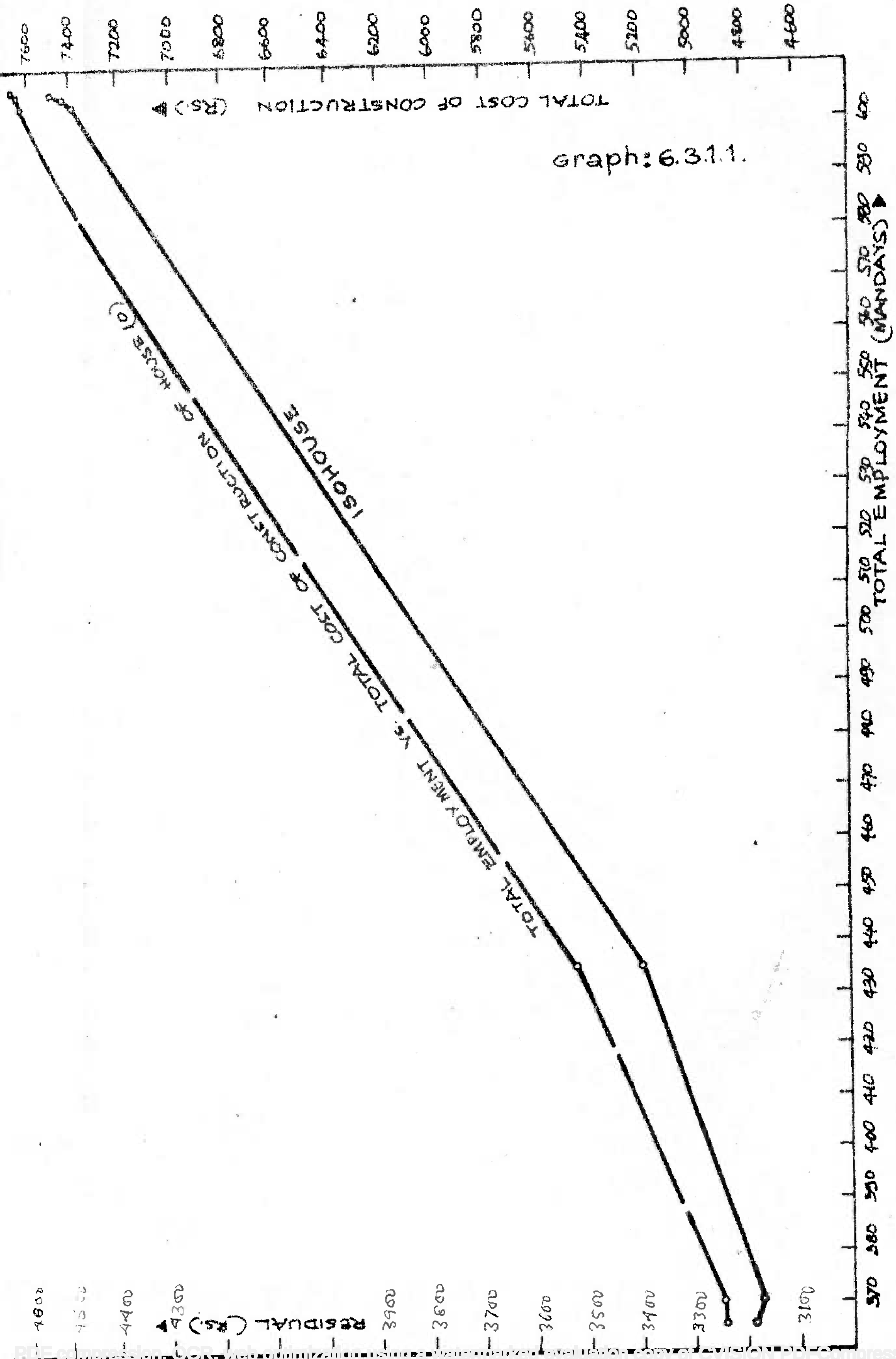
---

* 3186.21 - 3177.28 = 8.99

respectively for the solution III. Here, the expenditure on the capital per rupee value of the construction is the lowest and the employment-level per rupee value of the construction is the highest compared to all the other solutions. This implies that the expenditure on the capital per manday of the total-employment is the lowest for solution III. In this sense, this is the least-capital-intensive (or the most labour-intensive) solution of all of them. Now, can we assert that the solution III is the appropriate one if one is interested in providing the highest employment per rupee of expenditure on the cost of construction? It would seem that solution III is an inefficient solution requiring both more labour and more inputs. Yet under our definition of a house the inputs required for solution III may be quite different from inputs required for solution II and a change of relative price of some of the inputs may make solution III a desireable one. When government's ability to enforce certain policiesto redistribute income is limited, one might consider solution III an appropiate one. We will, however return to this question in a different exercise. (See the exercise on maximising the employment subject to a cost constraint).

Now, let us examine the share of the most unskilled labour in the total employment as the production technique-sets that provide higher levels of total employment are taken up. Table 6.3.1.1 shows that this share is consistently more than 50 percent for all such sets described there. However, this share decreases as the total employment increases. This is because the techniques of higher employment potential are relatively less intensive of unskilled labour compared to those with lower employment potential.

In the end, we will trace out the isohouse depicting the alternative sets of various techniques required in the production of the house. An isohouse represents the construction of a house of specified dimensions, providing a given level of functional utility. In this exercise, the employment is increased replacing other materials and rental on capital. These materials and capital are aggregated into one composite commodity (using their prices as weights) to facilitate the representation of the isohouse in a two-dimensional frame. Graph 6.3.1.1 shows the isohouse. X-axis represents total employment in mandays and Y-axis (leftside) represents the values of the aggregated commodity representing all the other materials and capital rental in terms of rupees. These values are the corresponding values of objective function net of the wage bill. The upward sloping nature of the isohouse is already explained in Chapter I (see page 8). If more than two inputs are considered, the isoquants (here the isohouse) might appear to be positively


TOTAL COST OF CONSTRUCTION (RS.)
7600
7400
7200
7000
6800
6600
6400
6200
6000
5800
5600
5400
5200
5000
4800
4600
ISOHOUSE
TOTAL EMPLOYMENT VS. TOTAL COST OF CONSTRUCTION OF HOUSE (a)
TOTAL EMPLOYMENT (MANDAYS)
370
380
390
400
410
420
430
440
450
460
470
480
490
500
510
520
530
540
550
560
570
580
590
600
RESIDUAL (RS.)
4600
4500
4400
4300
3900
3800
3700
3600
3500
3400
3300
3100

Graph: 6.3.1.1.

sloped, though still convex, in a two-dimensional frame (i.e. any one input versus a weighted sum of all the other inputs).

Initially there could be a substitution possibility between the materials (including capital) and the employment. After a certain stage, however, higher employment meant higher amounts of materials in the aggregate. The convex nature of the isohouse can clearly be observed. Implications of the marginal rate of substitution between employment (total) and the composite commodity can be understood from the Table 6.3.1.2 which provides the details for the six production-technique sets of table 6.3.1.1.

Table 6.3.1.2

Subsidy (Rs.)	Total Employment (mandays)	Increase over previous level (mandays)	Composite commodity or Residual (Rs.)	Increase over previous level (Rs.)
0	365.989	-	3186.20	-
1	369.74748	3.75848	3177.2066	-8.9934
9	434.98934	65.24186	3398.7721	221.5655
13.50	603.86837	168.87903	4496.7677	1097.9956
26	604.809	0.94063	4516.9445	20.1768
31	605.70394	0.89494	4540.4899	23.5454

Graph 6.3.1.1 shows also a plot between the level of total employment and the gross cost of construction. Following table shows the incidence of increasing the employment on the cost of construction of the house.

Graph: 6.3.1.2.

L/O Vs. TOTAL COST OF CONSTRUCTION OF HOUSE [O]

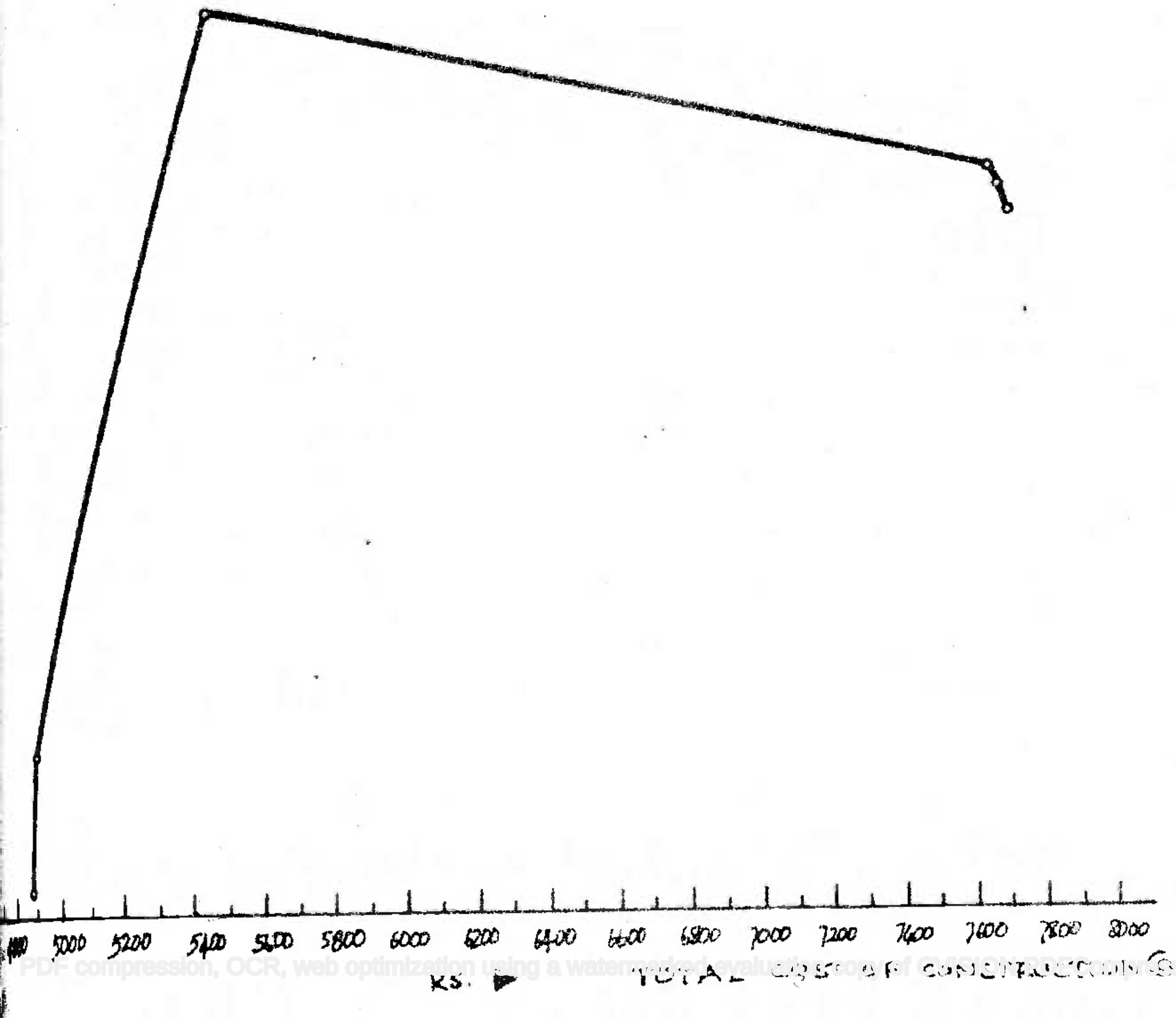


Table 6.3.1.3

Subsidy (Rs.)	Total Employment (mandays)	Percentage increase over the base level	Cost of construction (Rs.)	Percentage increase over the base level
0 (Base)	365.989	-	4882.57	-
1	369.74748	1.027	4886.22	0.075
9	434.98934	18.85	5443.13	11.48
13.50	603.86837	64.996	7638.65	56.45
26	604.809	65.25	7662.81	56.94
31	605.70394	65.5	7690.13	57.5

From the above table it can be concluded that the elasticity of cost of construction with respect to total employment is less than one.

6.3.2 <u>Sensitivity analysis with respect to the most unskilled labour force</u>: In the previous exercise, we addressed ourselves to test the sensitivity of the base solution with respect to a change in the level of subsidy given to increase the level of total employment. In doing so we observed that any changes made in the optimal technique sets providing higher levels of total employment are not seriously adverse to the share of the unskilled labour in the total employment, in the sense this share is always more than 50 percent. However, it is important to analyse the situation when the subsidy is given to increase the level of, not the total employment, but the employment of unskilled labour particular. Would the Technique sets selected conflict any way with the ones selected in the previous exercise? This exercise is devoted to analyse these aspects.

We have two types of unskilled labour force : direct and indirect (referred to as DL 1 and IL 1 respectively). While we seek to increase the employment of the unskilled labour force through these two sources, i.e. direct and indirect, the following questions would arise : should the subsidy be given for direct employment/indirect employment? or should it be given for both sorts of employment of this labour force simultaneously? As the aim is mere provision of employment for the unskilled labour force, it should hardly matter where and how it is provided: directly or indirectly. Hence subsidy was specified for both sorts of employment of the unskilled labour force and changes in the techniques sets were analysed. The exercise is carried out in the following way: A row corresponding to the most unskilled labour in the model is as follows:

$$GX - 1.0 \; S_g = 0 \qquad (1)$$

where 'g_j' s of G are given by

$$g_j = D_{1j} + N_{1j}$$

where D_{1j} and N_{1j} are the 1st rows corresponding to unskilled labour force from D and N matrices respectively.

This implies

g_j = total direct and indirect employment of the unskilled labour force required per unit operation of jth activity.

The modified objective function would be to

$$\text{Minimise } \phi = C \begin{bmatrix} T \\ X \end{bmatrix} - C_{Sg} S_g$$

where S_g denotes the total employment level of this unskilled labour force, and C_{Sg} is the amount of subsidy for every unit (i.e. manday) of this employment. For $C_{Sg} = 0$, the solution corresponds to the base solution.

This algebraic formulation of the constraint provides the same level of subsidy to direct and indirect unskilled labour.

C_{Sg} is given successively higher values. Table 6.3.2.1 reports the results obtained. A subsidy of Rs. 1.25 per manday changes the set of optimal techniques corresponding to the base solution. However, this change is simply the replacement of cement mortar by cement-lime mortar in the technique for external plastering. This change increases gross cost of construction by Rs. 3.65. But since the subsidy is far more than this increase (subsidy = 241.709x 1.25 = 302.136 Rs.), net cost of construction is less than that corresponding to the base solution. However, the builder will not find it to be financially beneficial to change the technique set for further increases in the subsidy, even upto Rs.11/-. This is because any changes in the set of techniques may not bring down the net cost

Table 6.3.2.1

Sensitivity Analysis with respect to the credit on the Most Unskilled Labour

Credit on DL1 and IL1 (Rs./per manday)	0	1.25	11.50	29.0	45.0
Amount -gross (G) (Rs) (cost of construction)	4883	4886	5252	6579	6631
Amount-net (Rs.)	4883	4504	2090	-2759	-7814
Capital (K) (Rs.)	690	684	689	1103	1107
Labour (L) (Rs.)	366	370	413	520	522
Electricity (KWh)	313	304	300	300	300
Coal (tonnes) (X10)	55	56	47	58	60
Limestone (tonnes)(X10)	96	99	116	12	12
Gypsum (tonnes) ($X10^3$)	156	152	150	150	150
Clay (tonnes) ($X10^2$)	6935	6933	4067	4067	4457
Water (tonnes) ($X10^2$)	1175	1140	1124	1124	1124
Ironore (tonnes)($X10^3$)	430	430	430	1493	1493
Manganesore (tonnes)($X10^3$)	29	29	29	102	102
Dolomite (tonnes) ($X10^3$)	20	20	20	71	71
Coarsesand (m^3) ($X10^2$)	1256	1256	1121	1011	1020
Finesand (m^3) ($X10^2$)	268	268	618	618	506
Quarraystone (m^3)($X10^2$)	1694	1694	4407	4166	4166
Miscellanous (Rs.)	931	926	923	1230	1253
Wage of DL1+IL1 (Rs.)	823	834	946	1109	1114
Residual (Rs.)	4060	4053	4306	5470	5517

DL1 + IL1 (mandays)	120+118	121+121	150+125	202+120	202+121
DL2 + IL2 ('')	24+13	24+13	25+ 8	24 + 8	24+ 8
DL3 + IL3 ('')	0+5	0+5	0+7	0+7	0+7
DL4 + IL4 ('')	40+ 7	40+ 7	61+ 6	117+6	117+6
DL5 + IL5 ('')	33+ 5	33+5	26+ 4	26+10	26 +10
DL6 + IL6 ('')	0+1	0+1	0+1	0+2	0+2
Optimal Levels of Techniques	148FBL= 2.7	148FBL= 2.7	148FBL= 4.3	148FBL= 4.3	148FBL= 4.3
	148FBP= 5.9	148FBP= 5.9	148FBP= 5.9	148FBP= 5.9	148FBP= 5.9
	111BFL= 2.9	111BFL= 2.9	111RFL=3.7	111RFL= 3.7	111RFL= 3.7
	111BFP =1.6	111BFP= 1.6	111BFP= 1.6	111BFP= 1.6	12LBFP= 1.6
	111BLW=14.0	111BLW=14.0	111RLW=18.5	111RLW=18.5	111RLW=18.5
	111BLP= 7.3	111BLP= 7.3	111BLP= 7.3	111BLP= 7.3	12LBLP= 7.3
	136BRF=41.8	136BRF=41.8	136BRF=41.8	124ORF=41.8	124ORF=41.8
	124FLG= 4.2	124FLG= 4.2	16BFLG= 4.2	16BFLG= 4.2	16BFLG= 4.2
	111PLI=16.6	111PLI=16.6	111PLI=16.6	111PLI=16.6	12LPLI=16.6
	16CPLE=10.0	129PLE=10.0	129PLE=10.0	129PLE=10.0	129PLE=10.0

of construction. However, if the subsidy is increased to Rs. 11.50 the house-builder adopts those techniques requiring more of unskilled labour. At this level, the techniques corresponding to the superstructure and foundation of load bearing walls and flooring are changed. Instead of brick masonry, random rubble masonry is adopted both in superstructure and foundation. It should be noticed that lime-surkhi mortar is not changed. Brick-flooring in 1:6 cement mortar replaced the cement-concrete flooring. Any more changes do not occur in the technique set for further increases in the level of subsidy upto Rs. 28.00.

However, if a subsidy of Rs. 29.00 per manday is provided, change in the technique set is brought through replacement of "136 BRF" roof technique by "1240RF" roof technique (see option list and Appendix A). Here the substitution possibilities between concrete and steel are taken advantage of. (Note "136 BRF" is a 'balanced' design and "124 ORF" is an 'overreinforced" design). This solution does not change even if subsidy is increased upto Rs.44.00. But if the subsidy is increased upto Rs. 45.00, again some more changes in the technique set are brought. The mortar used in building the superstructure and foundation of partition walls is changed to 1:2 (lime : surkhi) composition from 1:1:1 (lime: surkhi : sand) composition. Same holds with respect to internal plastering also.

Let us look at the employment aspects involved in the above changes from the table 6.3.2.2 below.

(a) A subsidy of Rs. 1.25 per manday can increase the employment of unskilled labour only by3.289 mandays over the base solution level.

(b) A subsidy of Rs. 11.50 per manday can increase the employment of this class by 36.338 mandays over the base solution level.

(c) Approximately, at least a subsidy of Rs.29.00 per manday should be given to increase the employment of this class by 83.034 mandays over the base solution level.

Thereafter again a further increase by Rs. 16.00 in the subsidy (i.e. Rs. 45.00 per manday) could bring only an increase of 0.156 mandays in the employment.

Table : 6.3.2.2

Subsidy level (Rs.per manday)	Employment of DL 1 and IL 1 (manday)	Increase over the base level (manday)	Increase over the previous solution level (manday)
0 (base)	238.42	-	-
1.25	241.709	3.289	3.289
11.50	274.758	36.338	33.049
29	321.454	83.034	46.696
45	322.61	83.190	0.156

From the above three points, it may be concluded that the policy of subsidising for increasing the employment of the most unskilled labour is not worth pursuing.

This conclusion can be corroborated in a different way also. Compare tables (6.3.1.1) and (6.3.2.1). For an approximately same level of total employment of the unskilled labour i.e. (DL 1 + IL 1), the technique sets in the former table provide a higher level of total employment also, than that provided by those in the latter table. This implies maximization of total employment follows through a simultaneous maximization of unskilled labour also, while the vice versa need not be true. Before drawing any policy conclusions based on these technical observations, however, economic implications also have to be noted. Let us designate the two policies as:

Policy A = To subsidise total employment,

Policy B = To subsidise unskilled labour.

Consider the following table 6.3.2.3 prepared from tables 6.3.1.1 and 6.3.2.1.

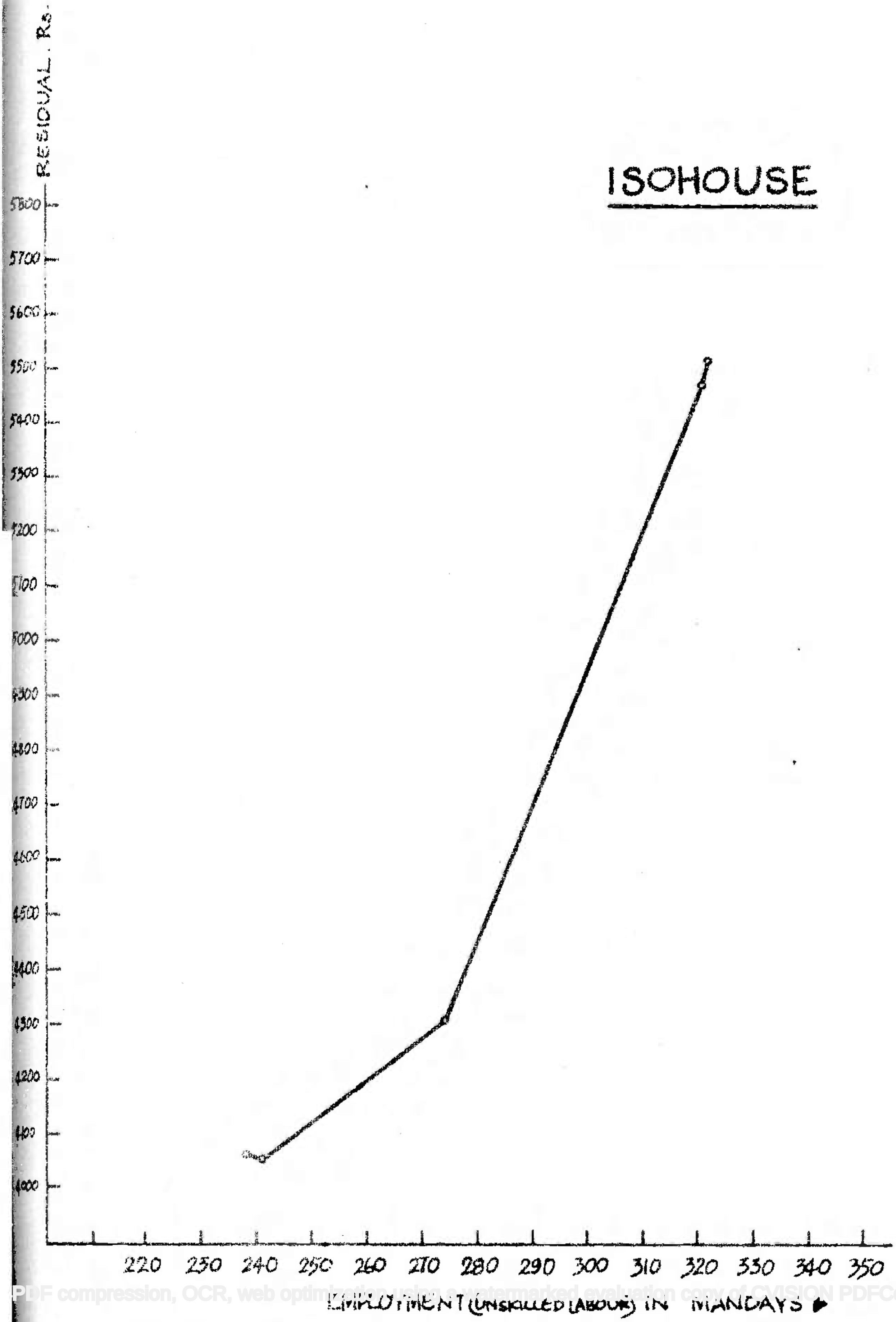
Table 6.3.2.3

	Policy A			Policy B			
DL 1+ IL 1 mandays	Total Employment mandays	Subsidy Level (Rs.)	Total subsidy (Rs.)	DL 1+ IL 1 man-days	Total Employment mandays	Subsidy level (Rs.)	Total Subsidy (Rs.)
241.70897	369.74748	1.00	369.75	241.709	369.747	1.25	302.14
274.36202	434.98934	9.00	3914.904	274.758	412.745	11.50	3159.72
321.68281	603.86837	13.50	8152.22	321.454	520.14	29.00	9322.17
322.2743	604.809	26.00	15725.03	322.61	521.976	45.00	14517.45
322.83751	605.70394	31.00	18776.82				

In case (i) obviously policy B is preferable because for the same levels of total employment as well as the employment of unskilled labour a smaller amount of total subsidy is incurred through policy B. In case (ii) also policy B is preferable because the extra level of total employment (22.24434 = 434.98934 - 412.745) is insignificant compared to the extra amount of total subsidy (755.184 = 3914.904 - 3159.72) incurred through policy A. However, in all the other cases it is not so. Policy A becomes preferable to policy B in the cases (iii) and (iv) because for substantial higher levels of total employment and the same level of unskilled labour, the amount of total subsidy incurred through policy A is less than that through B. Hence we may conclude that suitable economic policies that lead to maximize the total employment rather than only the unskilled labour should be evolved.

Again, let us suppose that the government bears the wage-bill corresponding to the unskilled labour instead of subsidising their employment. It implies that the unskilled labour are freely available for the house-builder and he can employ as many as of them he wants if it saves on the non-labour resources. In this case the solution corresponding to the subsidy-level of Rs. 1.25 instead of the base solution in the table 6.3.2.1 turns out to be optimal for him. It indicates that there exist some substitution possibilities between the unskilled labour and all the other resources.

Graph: 6.32.1.


ISOHOUSE
RESIDUAL . Rs.
5800
5700
5600
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
4400
4300
4200
4100
4000
220
230
240
250
260
270
280
290
300
310
320
330
340
350
EMPLOYMENT (UNSKILLED LABOUR) IN MANDAYS

We conclude the discussion on this exercise by presenting the isohouse displaying the substitution relations between unskilled labour force and other labour force and materials in building the specified house. Graph 6.3.2.1 represents employment of this labour in mandays on its X-axis and the "residual" in rupees on Y-axis. This residual which represents all the inputs other than the unskilled labour, aggregated into one composite commodity is obtained for each technique set selected in the following way:

Residual : Gross cost of construction - Wage bill corresponding to DL 1 and IL 1 (unskilled labour force)

Isohouse corresponds to building a specified house. In the initial stages of increasing the employment of the labour force in question, there are substitution possibilities between employment of this labour and the residual. However, mainly a complementary relation exists between them.

6.3.3 Sensitivity analysis with respect to interest-rate: The rental values on capital equipment required in the production of the intermediate inputs for building construction depend upon the assumed rate of interest. The base solution corresponds to an interest rate of 20 percent. Now, we seek to know the changes in the base solution i.e. changes in the production-techniques with respect to the changes in the rate of interest. We consider the following rates of

Table 6.3.3.1*
Sensitivity Analysis with respect to interest rate

Interest rate (i)(percent)	5	10	15	20	25
Objective value in Rs. (gross cost of contn. =0)	4500	4618	4742	4883	5029
Capital (K) (Rs.)	307	421	549	690	836
Labour (L)(mandays)	366	366	366	366	366
K/O (X 10^6)	68297	91238	115838	141255	166288
L/O (X 10^6)	81327	79324	77177	74958	72773
K/L (X 10^5)	83978	115019	150094	188445	228502
Optimal Techniques	148FBL. 148FBP	148FBL. 148FBP	148FBL 148FBP	148FBL, 148FBP	148FBL 148FBP
	111BFL. 111BFP	111BFL 111BFP	111BFL 111BFP	111BFL 111BFP	111BFL. 111BFP
	111BLW 111BLP	111BLW. 111BLP	111BLW, 111BLP	111BLW, 111BLP	111BLW, 111BLP
	136BRF 124FLG	136BRF. 124FLG	136BRF, 124FLG	136BRF 124FLG	136BRF, 124FLG
	111PLI 16CPLE	111PLI 16CPLE	111PLI. 16CPLE	111PLI 16CPLE	111PLI 16CPLE

interest for this purpose : 5 percent, 10 percent, 15 percent, 20 percent and 25 percent. Results are tabulated in table 6.3.3.1.

It can be observed that the base solution is the same for all the rates of interest. Different rental values on capital (K) merely indicate that the same equipment of capital is valued at different rates of interest. Further discussion of this exercise is avoided because the solution which is already explained in the previous pages, remains unchanged over the range of the interest-rates considered.

6.3.4 Sensitivity analysis with respect to cement price: In all the previous exercises, it is observed that in the optimal production techniques the use of cement has been kept low. Since the objective is minimization of cost, this reflects a high price of cement. In spite of such a high price, in the real world generally techniques using more cement are adopted. Given a price of 227.00 Rs. per tonne of cement, the optimal production techniques suggested by our model are thus in conflict with the ones adopted in the real world. Such a conflict can arise if the objective of the house-builders is not the same as postulated, namely minimising the overall cost of construction. In general, it is cement and its price that are very important in the field of construction. So changes in the optimal production techniques are important to observe, with variations in the price of cement. This exercise is devoted to this analysis.

This analysis is carried out in the following way: consider the 'B' matrix of our model:

$$\begin{array}{l|lll|}
 & \text{cement} & \text{bricks} & \ldots\ldots\ldots\ldots\ldots\ldots \\
\text{capital} & b_{11} & b_{12} & \\
\text{electricity} & b_{21} & b_{22} & \\
\text{coal} & b_{31} & b_{32} & \\
 & \vdots & \vdots & \\
 & \vdots & \vdots & \\
\text{miscellanous} & b_{k1} & b_{k2} &
\end{array} = B$$

Columns of this matrix represent inputs like cement, bricks etc. and rows represent K primary factors (or resources) like capital, electricity, coal etc. required in the production of the former inputs. The price of cement is fixed in our model, and we have the following relation:

$$\text{Price of Cement per tonne} = \sum_{j=1}^{K} (b_{j1} \times \text{price of jth resource})$$

where column b_{j1} corresponds to cement production. To take care of this relation, the last resource called "miscellaneous expenditure" is calculated as a residual in the following way:

$$\begin{array}{l} \text{Miscellaneous expenditure} \\ (b_{k1}) \text{ involved in the} \\ \text{production of a tonne} \\ \text{of cement} \end{array} = \begin{array}{l} \text{price of} \\ \text{cement per} \\ \text{tonne} \end{array} - \sum_{j=1}^{k-1} \left(b_{j1} \times \text{price of jth resource}\right)$$

For the base solution, b_{k1} corresponds to a price of cement of 227.00 Rs. per tonne and 20 percent rate of interest on the capital. Now the value of b_{k1} varies as the price of cement varies. In other words, by varying b_{k1}, the price of cement can be varied. The following prices of cement per tonne were considered for our analysis: 272.40 Rs. (20 percent increase over 1972 price of 227.00 Rs.), 249.70Rs. (10 percent increase), 204.30 Rs. (10 percent decrease), 181.60 Rs. (20 percent decrease), 158.90 Rs. (30 percent decrease), 136.20 Rs. (40 percent decrease) and 113.50 Rs. (50 percent decrease). Results obtained are displayed in table 6.3.4.1.

We discuss the results wrt the following:

a. Production techniques selected, and
b. implications for employment in general and of unskilled labour in particular.

(a) Production techniques

Of the seven cement-price variations considered, qualitative changes (i.e. one technique replacing another one completely) in the technique-set occurred at five instances. The variation in the techniques extended over the stages of internal plastering, external plastering, flooring, foundation and superstructure of load bearing walls as well as partition walls. No change occurred in the techniques of roof and foundation bed of the walls.

When cement price is increased by 10 percent, external plastering technique is changed. It is optimal to switch over to cement-lime plastering from cement

Table 6.3.4.1

Sensitivity Analysis with respect to the Price of Cement

Price of Cement per tonne (Rs.)	272	249	227	159	113
Objective Value in Rs. (cost of contn.=0)	5317	5059	4883	4604	4374
Capital (K) (Rs.)	668	684	690	725	821
Labour (L) in mandays	374	370	365	354	322
K/O (X 10^6)	125717	135177	141255	157516	187682
L/O (X 10^6)	70357	73090	74958	76893	73630
K/L (X 10^5)	178685	184946	188445	204851	254899
Cement required (tonnes)	3.5	3.8	3.9	4.5	6.1
Residual (Rs.)	4370	4110	3994	3887	3679
Electricity (Kwh)	278	304	313	361	490
Coal (tonnes)(x10)	58	55	55	53	50
Limestone (tonnes)(x10)	95	99	96	89	72
Gypsum (tonnes)(x10^3)	139	152	156	180	245
Clay (tonnes)(x10^2)	7953	6933	6935	6686	6365
Water (tonnes)(x10^2)	1043	1140	1175	1354	1837
Ironore (tonnes)(x10^3)	430	430	430	430	430
Manganeseore (tonnes)(x10^3)	29	29	29	29	29
Dolomite (tonnes)(x10^3)	20	20	20	20	20
Coarsesand (m^3)(x10^2)	1335	1256	1256	1250	1630
Finesand (m^3)(x10^2)	268	268	268	411	411
Quarrystone (m^3)(x10^2)	1531	1694	1694	1694	1694
Miscellaneous (Rs)	1299	1098	931	662	359

Table 6.2.4.1 (cont.)

DL 1 + IL 1 (mandays)	120 + 124	121 + 121	120 + 118	120 + 108	118 + 82
DL 2 + IL 2 "	25 + 15	24 + 13	24 + 13	24 + 13	23 + 12
DL 3 + IL 3 (")	0 + 5	0 + 5	0 + 5	0 + 5	0 + 0
DL 4 + IL 4 (")	39 + 7	40 + 7	40 + 7	40 + 7	40 + 7
DL 5 + IL 5 (")	33 + 5	33 + 5	33 + 5	33 + 5	33 + 5
DL 6 + IL 6 (")	0 + 1	0 + 1	0 + 1	0 + 1	0 + 2
Optimal Level of Techniques	148FBL = 2.7 148FBP = 5.9 111BFL = 2.9 111BFP = 1.6 111BLW =14.0 111BLP = 7.3 136BRF =41.8 16BFLG = 4.2 111PLI =16.6 129PLE =10.0	148FBL = 2.7 148FBP = 5.9 111BFL = 2.9 111BFP = 1.6 111BLW =14.0 111BLP = 7.3 136BRF =41.8 124FLG = 4.2 111PLI =16.6 129PLE =10.0	148FBL = 2.7 148FBP = 5.9 111BFL = 2.9 111BFP = 1.6 111BLW =14.0 111BLP = 7.3 136BRF =41.8 124FLG = 4.2 111PLI =16.6 16CPLE =10.0	148FBL = 2.7 148FBP = 5.9 111BFL = 2.9 111BFP = 1.6 111BLW =14.0 111BLP = 7.3 136BRF =41.8 124FLG = 4.2 16CPLI =16.6 16CPLE =10.0	148FBL = 2.7 148FBP = 5.9 16CBFL = 2.9 16CBFP = 1.6 16CBLW =14.0 16CBLP = 7.3 136BRF =41.8 124FLG = 4.2 16CPLI =16.6 16CPLE =10.0

plastering; that is part of the cement used inplastering is replaced by lime. When the price is further increased by 20 percent over the base price (i.e. to Rs. 272.40), it is found optimal by effecting a change in the flooring activities also. Plaincement-concrete flooring is found to be no more optimal. Brick-flooring in cement mortar is preferred. Some of the cement is replaced by bricks here. As expected, cement is being replaced by other materials when its price is increased.

However when price is decreased, the solution is unaffected by decreases upto 20 percent unlike in the case of similar increases. No change occurs in the optimal technique set when the price is decreased either by 10 or 20 percent. When cement — price is decreased far below, i.e. upto 30 per cent, then some increase in the consumption of cement has been brought due to a change in the internal plastering techniques. Here Lime-surkhi-sand internal plastering technique is replaced by cement-sand plastering. However, a further decrease in the price of cement, upto 40 percent below the base level, does not invite more-cement-consuming techniques to replace less-cement consuming techniques. No change occurred in the techniques-set by a further decrease in the price, upto 40 percent, from 30 percent below the base level. Now let us reduce the price of cement by half of its base level, i.e. cement costs only Rs. 113.50 instead of

Rs. 227.00 per tonne. It is observed that foundation and superstructure of the load bearing walls as well as partition walls are, better, built with cement-consuming techniques. The lime-surkhi-sand mortar is replaced by lean cement mortar implying it is profitable to substitute cement for lime and surkhi. This tells us that, even to use lean but not strong cement mortars (1:6, 1:4, 1:3 = cement:sand mortars are stronger in succession), the price of cement has to be decreased by at least half of the base level. Generally textbooks and handbooks on building construction advice 1:6 (cement:sand) cement mortar to be used in construction. In spite of it, it is common to find that the house-builders go for stronger mortars like 1:4 and 1:3 cement mortars. The price of cement at which such mortars become optimal has to be still lower.

Table 6.3.4.2 gives the incidence of the price of cement on the cost of the house.

Table 6.3.4.2

cement price (Rs.)	change in the price(percent)	cost of construction (Rs)	change in the cost (percent)
272.40	+ 20 p.c.	5316.701	+ 9 p.c.
249.70	+ 10 p.c.	5058.796	+ 4 p.c.
227.00	0	4882.57	0
204.30	- 10 p.c.	4793.66	- 1 p.c.
181.60	- 20 p.c.	4704.75	- 4 p.c.
158.90	- 30 p.c.	4604.19	- 6 p.c.
136.20	- 40 p.c.	4501.71	- 9 p.c.
113.50	- 50 p.c.	4374.00	- 12 p.c.

(b) Employment aspects:

Table 6.3.4.1 gives the figures for the total labour employment and the employment of the most unskilled labour.

Comparing with the maximum possible total employment of 606.32 mandays associated with the production set available in our model, changes in the price of cement seem to have very marginal influence on the level of the total employment. However, a higher price of cement is associated with a higher level of employment. This implies cement-consuming techniques are less employment-creating, whereas lime and surkhi techniques create a higher level of total employment. In fact, switching over to cement-consuming techniques from non/less cement-consuming techniques can retrench an employment of (374.065-322.058) 52.007 mandays, per house. Hence a hike in the price of cement can be helpful in two ways:

(i) because of the decreased demand for cement in housing construction, the cement saved can be diverted to better uses like dam works, irrigation works etc.

(ii) because of the switching over to non cement-consuming techniques, employment level can be increased.

The second of the above conclusions rests on the assumption that there would not be reduction in the level of construction-activity due to unavailability of cement at cheap rates; i.e. house builders substitute other materials for cement in building construction.

It can also be observed from table 6.3.4.1 that switching over to non/less cement-consuming techniques (i.e. as the price of cement is increased) increases the total employment of the most unskilled labour(DL 1 + IL11). The difference between the two extreme cases is ((120.257+124.238) - (117.577+81.595)) 45.323 mandays. Noting that the corresponding difference for the total employment is 52.007 mandays (see previous paragraph), we conclude that adoption of more cement-consuming techniques are particularly adverse to the employment of the unskilled labour.

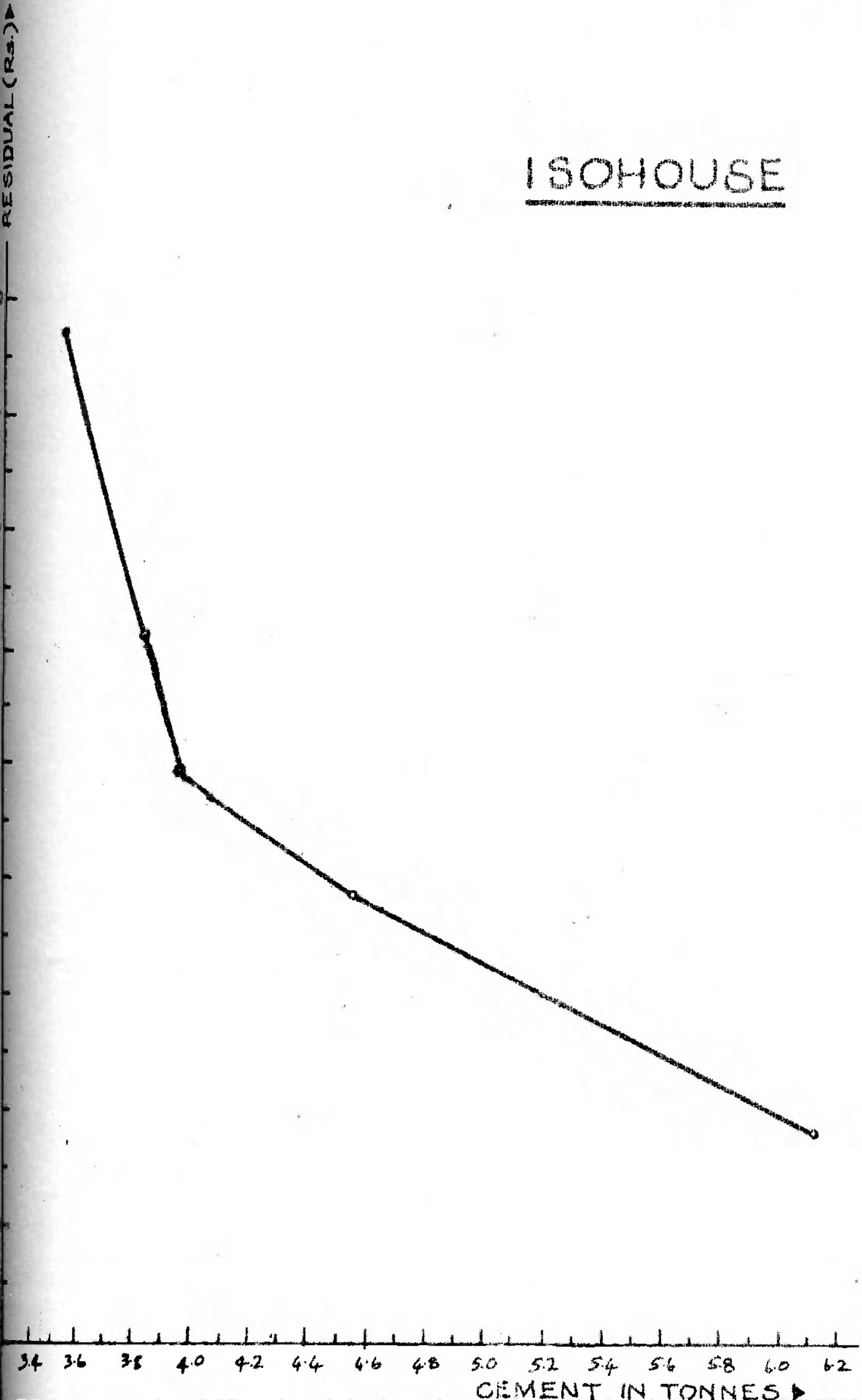
Let us look at the changes in the levels of DL 1 and IL 1 separately. The differences between the two extreme cases for DL 1 and IL 1 are (120.658-117.577) 3.081 and (124.238-81.595) 42.643 mandays. Thi explains that adoption of more cement-consuming techniques are generally adverse to the employment of the unskilled labour force and in particular to the indirect employment of this class. (This also explains the linkage effects of the construction sector, in regard to employment). Thus a hike in the price of cement seems to increase the employment of this labour through an increased demand for and production of other materials.

Summarising the above discussion, a hike in the price of cement can be advocated for the following reasons:

(i) It leads to higher employment in general.

(ii) It leads to higher employment of the unskilled labour force, thus contributing to a more egalitarian income distribution in the society.

Graph: 6.3.4.1.


ISOHOUSE
RESIDUAL (Rs.)
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
CEMENT IN TONNES

(iii) Demand for cement can be reduced from the housing construction sector and thus saved cement can be allotted to better uses, i.e. those uses where the value of social marginal product of cement is at least as large as the hiked price of cement.

(c) Isohouse

We conclude this analysis by presenting graphically the isohouse for the construction of the specified house, representing the substitution possibilities between cement and other materials and labour. This is displayed in graph . . . 6.3.4.1. Here the isohouse represents the production or construction of one house. X-axis represents tonnes of cement used in the construction. Y-axis represents the value of all the other materials and labour-services in rupees. This value is obtained as a residual in the following way for different production-technique-sets:

$$\text{Residual} = \text{cost of construction} - \left(\begin{array}{l}\text{total cement}\\ \text{required}\\ \text{(tonnes)}\end{array}\right) \times \left(\begin{array}{l}\text{price of}\\ \text{cement per}\\ \text{tonne}\end{array}\right)$$

The points on the isohouse represent different ways of combining cement and other materials. Any combination selected depends upon the price structure. Convex nature of the substitution of cement by other materials and labour can clearly be observed.

6 4 Maximizing the employment instead of minimizing the cost

So far in all our previous exercises we were minimising the total cost of construction subject to employment constraints of one sort of the other, and various other constraints. Different levels of subsidy were specified to increase the employment while minimising the net cost of construction, and the optimal levels of employment and the corresponding objective function values were observed. However, for these objective function values (of cost) are the observed optimal levels of employment also the maximum possible levels of employment? Is not it technically possible to generate higher levels of employment for the same values of the objective function? In other words what is the maximum possible employment subject to a cost constraint? We would like to know whether the solutions in the former exercise of parametric variation of the level of subsidy to increase the total employment while minimizing the cost are exactly same as the ones in this exercise of maximising the employment subject to a cost constraint. This exercise is devoted to answering this question.

The model has not been changed significantly except that the previous objective function now becomes a constraint of "less than or equal to" in nature, and the previous total-employment constraint now becomes the objective function to be maximized. Mathematically

$$\text{Maximise} \quad LX$$
$$\text{Subject to} \quad C \begin{bmatrix} T \\ X \end{bmatrix} \leq \bar{C}$$

and all the other constraint remaining same as described in chapter IV; and $\bar{C}$ is the specified level of cost of construction.

In the cost-minimization exercise the base solution costs us Rs. 4882.57. We observed that by offering a credit for every unit of the total employment to increase its level, the minimum possible gross cost of construction for the maximum possible total employment is Rs. 7690.13. In this exercise of maximizing the employment subject to a cost constraint, cost of construction ($\bar{C}$) is allowed to vary within this range. $\bar{C}$ is given the following values in succession, and the production techniques are observed: Rs. 4883.00, Rs. 5445.00, Rs. 6000.00, Rs. 6500.00, Rs.7000.00 Rs. 7691.00. The results obtained were tabulated in table 6.4.1. A comparison of table 6.4.1 with table 6.3.1.1 shows that the changes in the technique sets are occuring in the following order in both the situations:

(1) Cement-plastering is replaced by cement lime plastering for external plastering (16 CPLE is replaced by 129 PLE gradually).

(2) Cement concrete roof 'balancingly'reinforced with steel is replaced by cement concrete roof over reinforced with steel (136 BRF is replaced by 124 ORF gradually).

(3) Plain cement-concrete flooring is replaced by brick flooring which is again replaced by finely deressed stone flooring (124 FLG is replaced by 16 BFLG which is again replaced by 15 FFLG gradually).

(4) Brick-foundation and brick-superstructure in lime surkhi mortar are replaced by stone built foundation and stone-built superstructure in lime surkhi mortar for load bearing walls (111 BFL, 111 BLW are replaced by 111 CFL, 111 CLW gradually).

Table 6.4.1

Maximizing Total Employment (L) with a cost constraint

Labour (L)(objective value in mandays)	366	435	480	521	559	606
Amount(O) (cost of construction in Rs.)	4883	5445	6000	6500	7000	7691
Capital (K) (Rs.)	689	691	864	1020	1140	1167
K/O (X 10^6)	141103	126873	143952	156841	159911	151723
L/O (X 10^6)	75041	79916	80005	80072	79802	78755
K/L (X 10^5)	188033	158759	179928	195874	200385	192651
Electricity (Kwh)	313	300	300	300	301	303
Coal (tonnes)(X10)	55	46	50	55	56	55
Limestone (tonnes)(X10)	96	112	114	115	116	116
Gypsum (tonnes)($X10^3$)	156	150	150	150	150	151
Clay (tonnes) ($X10^2$)	6935	4028	4028	4028	3757	3391
Water (tonnes)($X10^2$)	1171	1124	1124	1124	1127	1135
Ironore (tonnes)($X10^3$)	430	432	876	1276	1493	1493
Manganeseore (tonnes)(10^3)	29	29	60	87	102	102
Dolomite (tonnes)($X10^3$)	20	20	41	60	71	71
Coarsesand (m^3) ($X10^2$)	1256	1120	1074	1032	999	979
Finesand (m^3) ($X10^2$)	268	584	584	584	584	471
Quarrystone (m^3)($X10^2$)	1694	4896	4796	4705	4655	4655
Sandstone (sq.m.) ($X10^2$)	0	0	0	0	1215	4600
Miscellaneous (Rs.)	931	909	1037	1153	1212	1223

Table 6.1.1 (cont.)

DL_1+IL_1(man-days)	120+119	152+122	174+120	194+118	206+115	212+111
DL_2+IL_2('')	24+ 13	25+ 8	25+ 8	24+ 8	28+ 8	38+ 7
DL_3+IL_3('')	0+ 5	0+ 6	0+ 6	0+ 6	0+ 6	0+ 6
DL_4+IL_4('')	40+ 7	84+ 6	107+ 6	128+ 6	139+ 6	136+ 5
DL_5+IL_5('')	33+ 4	26+ 4	26+ 7	26+ 9	40+ 10	79+ 10
DL_6+IL_6('')	0+ 1	0+ 1	0+ 1	0+ 2	0+ 2	0+ 2
Optimal levels of Techniques	148FBL=2.7	148FBL= 4.3	148FBL= 4.3	148FBL= 4.3	148FBL= 4.3	148FBL= 4.3
	148FBP=5.9	148FBP= 5.9	148FBP= 5.9	148FBP= 5.9	148FBP= 5.9	148FBP= 5.9
	111BFL=2.9	111CFL= 3.7	111CFL= 3.7	111CFL= 3.7	111CFL= 3.7	
	111BFP=1.5	111BFP= 1.6	111BFP= 1.6	111BFP= 1.6	111BFP= 1.6	111CFL= 3.7
	111BLW=14.0	111CLW=18.5	111CLW=18.5	111CLW=18.5	111CLW=18.5	12LBFP= 1.6
	111BLP=7.3	111BLP= 7.3	111BLP= 7.3	111BLP= 7.3	111BLP= 7.3	111CLW=18.5
	136BRF=41.8	124ORF= 0.1	124ORF=17.5	124ORF=33.3	124ORF=41.8	12LBLP= 7.3
	124FLG=4.2	136BRF=41.7	136BRF=24.3	136BRF= 8.5	16BFLG= 3.1	124ORF=41.8
	111PLI=16.6	16BFLG= 4.2	16BFLG= 4.2	16BFLG= 4.2	15FFLG= 1.1	15FFLG= 4.2
	16CPLE=8.9	111PLI=16.6	111PLI=16.6	111PLI=16.6	111PLI=16.6	12LPLI=16.6
	129PLE=1.2	129PLE=10.0	129PLE=10.0	129PLE=10.0	129PLE=10.0	129PLE=10.0

(5) Mortar with which the foundation and superstructure of partition walls are built is changed from lime-surkhi-sand to pure lime-surkhi (111 BFP and 111 BLP are replaced by 12 LBFP and 12 LBLW).

(6) Mortar used for internal plastering is changed from lime-surkhi-sand to lime-surkhi one (111 PLI is replaced by 12 LPLI).

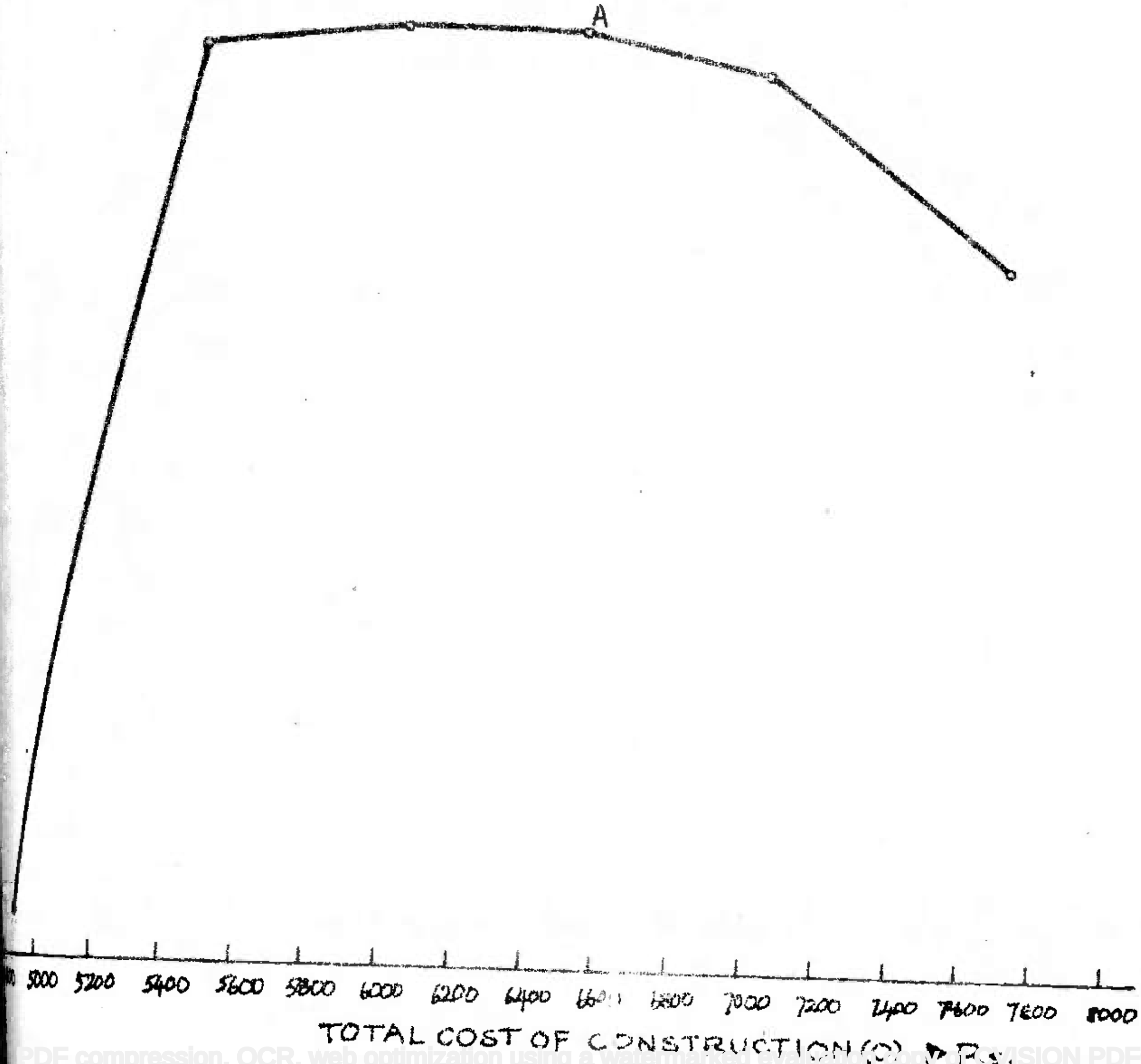
Above characteristics are observed to be the same whether we maximize employment subject to a cost constraint or we minimize the cost subject to an employment constraints (or credit on employment). This implies that the observed optimal levels of total employment generated through a subsidy given to increase its level while minimising the cost of construction are infact the maximum possible levels also, for those corresponding costs.

Now let us return to the question that is raised in the first parametric programming exercise: What is the proper set of techniques if one wants to maximise labour per rupee of expenditure (i.e. L/O). We could not answer this question in that exercise because, there employment is not maximised. Now that the total employment is maximised, such a set of techniques can be suggested. Strictly speaking this might involve a nonlinear programming exercise where L/O is directly maximised subject to different constraints. However now that the situations behind tables 6.3.1.1 and 6.4.1 are the same the information from these tables can be clubbed together, Also, since wide variations of cost and employment levels are covered, the need for such an exercise can be avoided. These tables present the values of L/O corresponding to various techniques-sets and costs. Graph 6.3.1.2 corresponds to table 6.3.1.1 and graph 6.4.1 to table 6.4.1. The vertical axes in these graphs denote L/O i.e. mandays per rupee expenditure and the horizontal axes, the total amount of expenditure on construction. Both these plots show that employment per rupee expenditure initially increases and reaches a maximum level (for example point A in graph 6.4.1) as the house builder spends more on the construction of the same house. If the expenditure goes beyond this level, other materials dominate over the labour services and hence L/O falls. Comparing graphs 6.3.1.2 and 6.4.1 or the corresponding tables, we might conclude that the production technique-set corresponding to Rs. 6500/- of gross cost of construction (see table 6.4.1) is the proper one for maximising labour services per rupee expenditure spent on construction. This set creates an employment of more than 0.08 mandays per every rupee spent. One can again workout the optimum subsidy (or credit) to be given to the builder to make him adopt this technique set.

We conclude the discussion on this exercise by presenting a plot which shows the relation between total cost of construction and the employment in total. This is given in graph 6.4.2. The vertical axes corresponds to

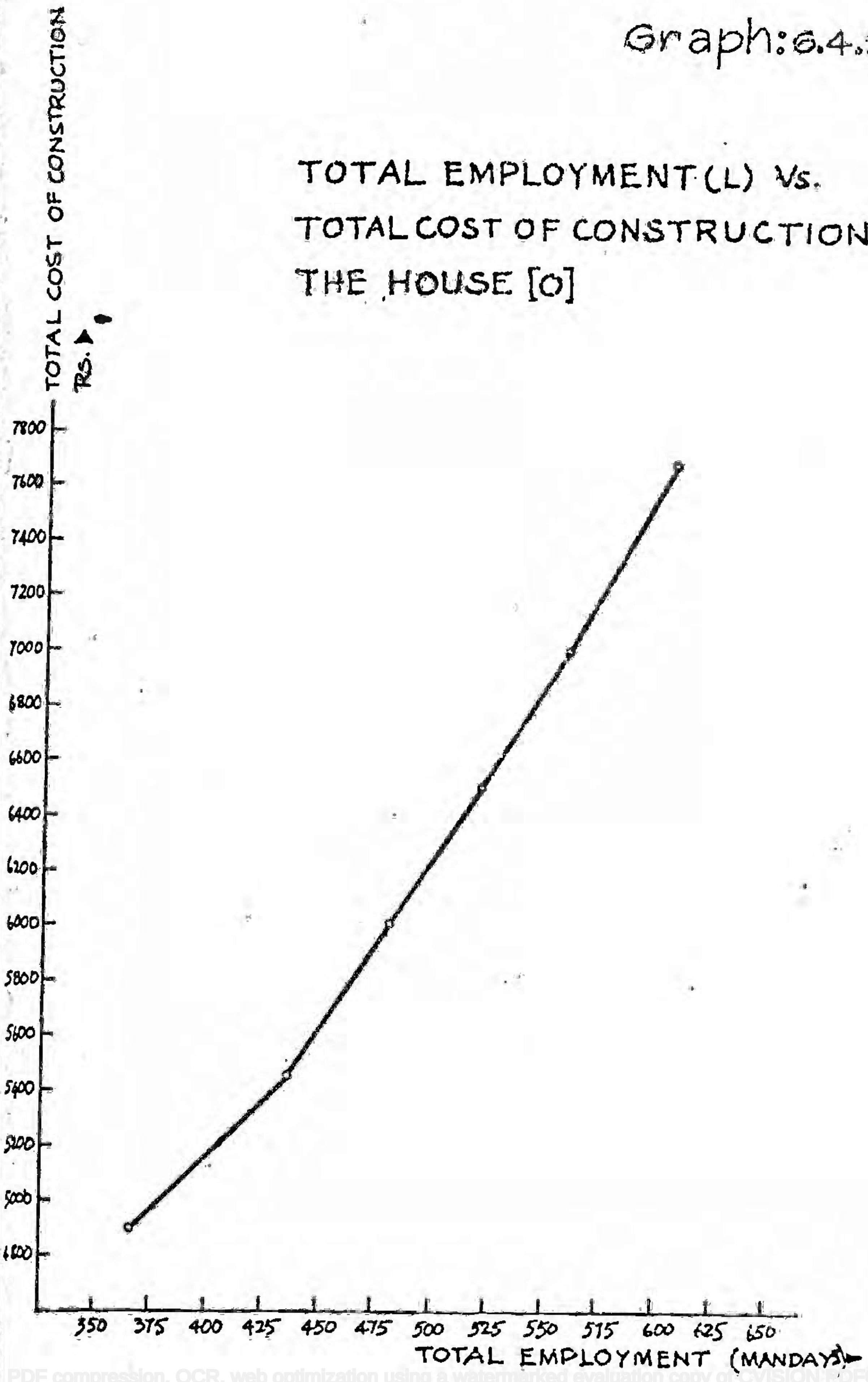
Graph: 6.4.1.

L/O Vs. TOTAL COST OF CONSTRUCTION OF THE HOUSE [C



Graph: 6.4.2.

TOTAL EMPLOYMENT (L) Vs. TOTAL COST OF CONSTRUCTION OF THE HOUSE [O]



total cost of construction and horizontal axis to total employment. Table 6.4.2 provides the interrelation between increasing the employment and the cost of construction.

Table 6.4.2

Cost of construction (Rs.)	Percentage increase over the base level	Employment total (mandays)	Percentage increase over the base level
4882.57	-	365.989	-
4883.00	0.008	366.427	0.0027
5445.00	11.52	435.14	18.89
6000.00	22.89	480.03	31.16
6500.00	33.13	520.47	42.21
7000.00	43.37	558.615	52.63
7691.00	57.52	605.708	65.50

From the above table it can be concluded that the elasticity of cost of construction with respect to employment is less than one, a result which is already obtained in exercise 6.3.1

6.5 Conclusions for Building Construction

In this exercise we summarise some of the important conclusions drawn from the previous exercises on building construction.

A house of brick-masonry is cheaper than that of stone-masonry or precast block masonry. According to the base solution, the costs on labour and materials amount to one-third and half respectively of the total cost of construction of the house. At an interest-rate of 20 percent, capital costs constitute only 14 percent of the total cost. At the prices prevailing in 1972 the techniques using lime and surkhi are cheaper than those using cement, for single storey housing construction. 40 percent of the total employment generated by construction programme is indirect. The most unskilled labour forms 65 percent of the total employment. Share of the most unskilled labour is significantly high both in direct and indirect employments separately.

By changing the technical specifications without affecting the functional utility of the house the level of total employment and the employment of the most unskilled labour can be increased. To compensate the additional cost of construction involved in such a change of technical specifications suitable economic policies may have to be devised. The elasticity of cost of construction with respect to total employment is less than one. The techniques of higher employment potential are relatively less intensive of unskilled labour compared to those with lower employment potential. There exist substitution possibilities between employment (both total and of the most unskilled labour) and the materials.

The base solution is insensitive with respect to the range of interest-rates that is considered. However, it is sensitive with respect to a change in the price of cement per tonne. A hike in the price of cement is desired because (i) it leads to higher total employment, (ii) it leads to higher employment level of the unskilled labour thus contributing to a more egalitarian income distribution in the society and (iii) demand for cement can be reduced from the housing construction sector and thus saved cement can be allotted to better uses where the social marginal product of cement is at least as large as the hiked price of cement.

The levels of employment indicated by the solutions corresponding to the objective of minimising the total cost of construction are in fact the maximum possible levels also for those corresponding costs. However the base solution does not maximise the total employment per rupee of expenditure (L/O) on cost of construction.

Part II

ROAD CONSTRUCTION

6.6 Appropriate Technology for Road Construction

The problem on road construction had the following number of constraints:

Resource constraints	14
Direct and indirect Employment Constraints according to wage groups	6
Total Employment constraints	1
Technical constraints	5
Output constraints	3
	29

and the following number of structural (other than slack) columns:

Resource activities	14
Production activities	13
	27

The road that has been selected for this project work has been, as already mentioned in chapter I, one kilometre long national highway. Its other main characteristics are the following:

Formation width	12 metres
Carriage way width	7 metres
Wheelload	12000 lb.

Other technical details are given in Appendix A.

Part II consists of sections 6.6 to 6.10. Section 6.7 deals with the discussion of the base(initial) solution.

Section 6.8 deals with the discussion of the sensitivity analysis (parametric programming) and related issues.

6.7 The Base Solution for Road Construction

For the base solution, we fixed the c.b.r.* to be 15. Life of asphaltic road is taken to be 8 years whereas all the concrete roads are assumed to be of 24 years life**. Maintenance costs for concrete roads are nil, but for asphalt roads they are assumed to be 5 percent of the cost of construction of premix carpet and sealing coat("PRCRPT" and "SLCOAT") activities. Interest rate on capital equipment is taken to be 20 percent. Same interest rate is used for discounting all the future costs incurred in the case of asphalt roads. Following is the base solution obtained:

Table 6.7.1 : The Resource and Production Activities of the Base Solution

Objective Function (Minimized cost) (O) = Rs. 114056.99

Resource Activities:

Capital rental (K) = Rs. 9413.193   Quarrystone = 2556.927 m^3

Electricity = 5.676 Kwh   Diesel = 873.96 tonnes

Coal = 2.041 tonnes   Bitumen = 38.586 tonnes

Coarse sand = 7.972 m^3 Moorum = 213.36 m^3

Miscellaneous Expenditure = Rs.182.43

Production Activities

LABEXC = 17540.676   WBMCDM = 533.4

PREPSG = 120.0   PRCRPT = 106.298

SOLING = 1066.8   SLCOAT = 106.298

---

* c.b.r. (California Bearing Ratio), a number expressed in terms of percentage indicates nature of the soil on which the road is built. See Appendix A.

** See the exercise on alternative life for concrete road. See appendix A for details regarding the treatment of different life times of different roads.

A description of the above production activities is given later.

The length of the road is one kilometre. Then, it implies that the cost of national highway construction is (114056.99/1000) Rs.114.06 per metre at 1972 prices. This includes capital cost, wage bill and materials cost. Capital cost is Rs. 9413.19 which forms 8.253 percent of the total cost. K/O is 0.08253, where K is cost of rental on the fixed capital and O is the total cost of road construction. See table 6.8.5.1. Corresponding wage bill is Rs.43211.613 which comes to 37.89 percent of the total cost*. That implies, materials amount$ to 53.86 percent of the total cost. In other words, while wage bill amounts to more than one-third and materials amount to more than one-half of the total cost of road construction, capital cost, direct and indirect, amounts to relatively a very small part of it.

The resources required in terms of physical units for making this road obtained from the solution are given above. The levels of those primary resources imply a certain amount of each of the intermediate inputs like cement, surkhi, etc. which are required in actual road construction.

The production activities selected are as follows:

---

* Full details of the base or initial solution can be seen in the Table 6.8.5.1. See the case corresponding to i = 20 percent.

(i) The labour-intensive technique for earth-excavation work is preferred to the capital-intensive technique. The capital-intensive technique employs a bulldozer of 90 horsepower, whereas the labour intensive technique employs simple tools like shovel, pickaxe, wheel barrow, bull cart etc. For every cubic metre of earthwork done, the labour intensive technique provides employment of 0.3006 mandays whereas the capital-intensive technique provides employment of only 0.00453 mandays.

(ii) Preparation of subgrade: Subgrade is the soil foundation receiving the traffic loads directly from the pavement. It is the surface of the natural ground (in its final shape after completion of earthwork) on which the entire road structure rests. Preparation of subgrade includes bringing it to the required camber and consolidation with road roller after excavating the earth to an average of 22.5 cm. depth. For this work there is only one technique. Hence, the activity "PREPSG" is restricted to be selected at the required level.

(iii) Soling: After preparing the subgrade, soling work is taken up in the case of asphalt roads whereas subbase is laid in the case of all concrete roads. Soling is a 6" thick (i.e. 15.24 cm.) layer packed with smaller stones and rolled over. The initial solution provides soling and implies that asphalt roads are preferred for national highways. Function of soling is to spread uniformly the traffic loads and weight of the road structure above itself, and hence to protect the subgrade.

(iv) Water bound macadam: In the case of asphalt roads, this work is taken up after soling work has been completed. This work implies laying a surface layer of a road in which the road metal has been consolidated with water and earthy material or rock particles. Stone fragments are first interlocked by rolling and then bound with smaller stone, gravel etc. Which is forced into the interstices by brooming, watering and rolling. This surface layer is 3" (7.62 cm.) thick.

(v) Premix carpet: This is nothing but a surfacing obtained by laying bitumen with stone aggregate of proper size to a thickness of more than an inch. Here it is 2.5 cm. thick.

(vi) Sealing coat: This is nothing but dressing of bitumen applied to open textured bituminous surfaces to render the surface watertight and strengthen the macadam. Thickness of this coat is about 1/2".

As mentioned earlier, it is clear from the above solution that asphalt roads are preferred for building national highways. In India most of the national highways are built with bitumen. Thus our solution conforms to the general practice, Relatively cheaper prices* of the materials required in asphlat road construction make this road preferable even though its life is much shorter and also requires some amount of maintenance expenditure compared to a concrete road. However, a bitumen road provides a smoother ride than a concrete road which has expansion joints every few feet.

Our solution provides an employment of 11359.154 mandays. The corresponding wage bill is Rs. 43211.61. The following table shows the details of the employment, direct and indirect, according to the wage group classification.

Table 6.7.2. Employment details of the base solution of road construction

Income group	Direct Employment	Mandays	Indirect Employment	Mandays
0 - 4 Rs/day	DL 1	7798.51	IL 1	1785.648
4 - 5 Rs/day	DL 2	489.953	IL 2	Nil
5 - 6 Rs/day	DL 3	1136.636	IL 3	Nil
6 - 8 Rs/day	DL 4	Nil	IL 4	44.013
8 -10 Rs/day	DL 5	89.721	IL 5	14.671
≥ 10 Rs/day	DL 6	Nil	IL 6	Nil
	Total	9514.820		1844.332

The table above implies that the base solution creates approximately 20 percent more employment indirectly in addition to direct employment (1844.332/9514.82 =0.1938).

---

* See the exercise on the variation of the price of bitumen.

The total indirect employment forms 16.24 percent of the total (direct and indirect) employment. The role of indirect employment appears to be less significant in road construction compared to that in building construction, where indirect employment forms around 40 percent of the total employment.

Let us observe the composition of employment. DL 1' and IL 1 are the least paid wage-earners. Their total employment (i.e. DL 1 + IL 1) is 9584.159 mandays. This is roughly 85 percent of the total employment of 11359.14 mandays. It means that the major bulk of the employment generated through road construction belongs to the lowest wage class earning less than Rs. 4.00 a day.

Looking at the figures of direct employment, the most unskilled labour force comes to 82 percent approximately of the total direct employment (7798.51/9514.82 = 0.8196). The corresponding figure for indirect employment is 97 percent approximately (1785.648/1844.332 = 0.9682). The very high percentage of this labour in indirect employment is not surprising because, the work of blasting, dressing, crushing etc. of quarry stone requires mostly unskilled labour. For asphalt road stone is the most important input; it is required in soling, waterbound macadam and premix carpet activities. Thus the base solution indicates a high proportion of the most unskilled labour in both direct and indirect employments separately.

In summary, the major conclusions drawn from the above discussion are as follows:

(a) Labour costs and materials' costs amount to more than one third and one-half of the total cost of road construction respectively.

(b) Capital costs amount to less than ten percent of the total cost of road construction, at 20 percent interest rate.

(c) Roughly 16 percent of the total employment generated by road construction is indirect.

(d) Bulk of the total employment generated by road construction accrues to the lowest-wage group (85 percent of the total).

(e) Share of the most unskilled labour (belonging to lowest wage group) in both direct and indirect employments is very high (82 percent and 97 percent respectively).

(f) For national highways an asphalt (bituminous) road is preferred to a concrete road.

6.8 Sensitivity Analysis for Road Construction

Section 6.7 presented and interpreted the base solution. In section 6.3 we stressed the importance of testing the sensitivity of the base solution with respect to changes in certain parameters. For the exercise on road construction also, we have conducted a sensitivity analysis. Essentially the following kind of parametric programming exercises have been carried out:

(1) Alternative interest-rates on capital,

(2) Alternative levels of subsidies on total employment generated,

(3) Alternative levels of subsidies on the employment of the most unskilled labour,

(4) Alternative prices of bitumen per unit (tonne),

(5) Alternative natures of the soil where the road is built,

(6) Alternative life for concrete roads; and finally

(7) Change the objective function to maximising the employment generated subject to a cost constraint from minimising the total cost subject to the employment constraints. In this exercise parametric variation is done with respect to total cost of road construction.

The variants are taken up one by one for discussion in the following pages:

6.8.1 Sensitivity analysis with respect to Total Employment: The need and methodology of this exercise are similar to that for building construction. Mathematically, S_t which denotes the total employment generated is defined by the following equation.

$$LX - 1.0\ S_t = 0 \qquad (1)$$

The objective function becomes

$$\text{Minimise } C = C \begin{bmatrix} T \\ X \end{bmatrix} - C_{st} \cdot S_t \qquad (2)$$

where C_{st} (the cost coefficients of the newly introduced variable S_t in the objective function) denotes the subsidy given per unit of the total employment. (2) implies that net cost of construction (i.e. gross cost of construction minus total subsidy) is minimized. For $C_{st} = 0$ (i.e. no subsidy) solution corresponds to the base solution and net cost is equal to gross cost. Now C_{st} is given various values and changes in the employment levels are observed.

Table 6.8.1.1 shows the resultsobtained.

It is observed that till C_{st} is raised to a value of Rs. 22/- per unit, no change in the solution takes place. It means that set of optimal production techniques is not changed implying that the total employment is not increased even if a subsidy of Rs. 22/- per unit (manday) is given. Total employment remains stationary at 11359.154 mandays.

However, when the subsidy is raised to Rs. 23/- per manday the set of production techniques is changed. Puzzolana concrete road with a lime-concrete subbase (PUZWCT and 111 SBP) is preferred to a bituminous road, as the former road has a higher employment potential of 5957.932 mandays (17317.086-11359.154) per kilometre length of the national highway compared to the latter road (i.e. base solution). The increase in the gross cost of construction due to such a change of techniques is compensated by the total subsidy. At this level of subsidy the gross cost of construction is Rs. 249262.19 and the total employment level is 17317.086 mandays per kilometre length of the road.

For further increase in the total employment level, the raise in the subsidy level required per mandays is observed to be abnormal. In fact, it is Rs. 750.00. Such a level of subsidy is of no practical relevance. Here the total employment level is 17349.574 mandays and gross cost of construction is Rs. 273388.87; the road is built with

Table 6.8.1.1*

Sensitivity Analysis with respect to credit on total employment

i = 20% CBR = 15 5% maintenance costs on asphalt roads
Concrete roads' life = 24 years

Credit on total employment (Rs./manday)	0	28.0	750.0
Objective values in Rs. (gross cost of constn.=0)	114057	249262	273389
Capital (K) (Rs.)	9413	46353	55262
Labour (L) (mandays)	11359	17317	17350
K/O (X 10^6)	82531	185962	202138
L/O (X 10^6)	99592	69473	63461
K/L (X 10^5)	82869	267674	318522
DL1 IL1/L (X 10^6)	343739	824251	818279
Electricity (Kwh)	6	34593	43241
Coal (tonnes)	2	180	206
Limestone (tonnes)	0	617	742
Gypsum (tonnes)	0	17	22
Clay (tonnes)	0	322	225
Water (tonnes)	0	1297	1622
Coarsesand (m^3)	8	757	754
Finesand (m^3)	0	101	101
Quarry stone (m^3)	2557	2131	2131
Diesel (litres)	874	117	117
Bitumen (tonnes)	39	0	0
Moorum (m^3)	213	0	0
Miscellaneous (Rs.)	182	62177	74944
Total wage bill (r.)	43212	67961	68636
Residual (Rs.)	70845	181301	204753

Table 6.8.1.1 : (cont.)

DL1 + IL1 (mandays)	7799+1786	8440+5834	8440+5757
DL2 + IL2 (")	490+0	911+ 22	911+ 22
DL3 + IL3(")	1137+0	1137+ 112	1137+ 112
DL4 + IL4 (")	0+ 44	111+ 296	111+ 343
DL5 + IL5 (")	90+ 15	174+ 163	174+ 196
DL6 + IL6 (")	0+0	0+ 117	0+147
Optimal Levels of Techniques	LABEXC=17541 PREPSG=120 SOLING= 1067 WHICDH= 533 PRCRFT= 106 SLCOAT= 106	LABEXC=17541 PREPSG=120 111SBF= 533 FUZWCT= 1689	LABEXC=17541 PREPSG=120 111SBC= 533 124WCT= 1689

cement concrete wearing coat (124 WCT) over a lime concrete subbase (111 SBC).

Now, suppose the government bears the entire wage-bill instead of announcing a subsidy level per manday. In that case the road-builder would minimize simply the cost of non-labour resources. These costs are presented as residuals (gross cost of construction - wage bill) in table 6.8.1.1. We find that the base solution itself is the optimal solution in this case also. That means the solution which minimises the gross cost of construction minimises also the cost of non-labour resources and the wage-bill separately. There exists complementarity between them.

Now, let us examine the share of the most unskilled labour in the total employment as the production techniques providing higher level of total employment are taken up gradually. Table 6.8.1.1 shows that this share is consistently more than 80 percent for all the different sets of production techniques. However, this share is decreasing as the total employment increases. This implies that the techniques of higher employment potential in the road construction are less intensive towards the most unskilled labour. Thus the marginal share of the most unskilled labour is less than the average share.

In the end, let us trace the isoroad representing alternative sets of different production techniques required in the production of one kilometre long road. Isoroad corresponds to construction of a national highway of one kilometre length with specified characteristics (wheel load, formation and carriage way width etc.) In this exercise employment is increased replacing or adding other materials and capital. These materials and capital, just as in the case of building construction, are aggregated into one composite commodity using their prices as weights. This facilitates a two-dimensional representation of an isoroad. X-axis represents total employment in mandays and Y-axis represents the values of the aggregate commodity representing other materials and capital in terms of rupees. These values are obtained by substracting the wage bills from the objective function values for each optimal set of production techniques. Graph 6.8.1.1 shows the isoroad.

The convex nature of the isoroad can be clearly observed. However the upward sloping nature of the curve implies that the higher employment can be provided only with a higher amount of the composite commodity (i.e. all the other materials put together as a weighted sum. Following table reveals the marginal rates of "substitution" (in fact, complementarity) between total employment and the composite commodity for the three different sets of production techniques.

Graph:6.8.1.1.

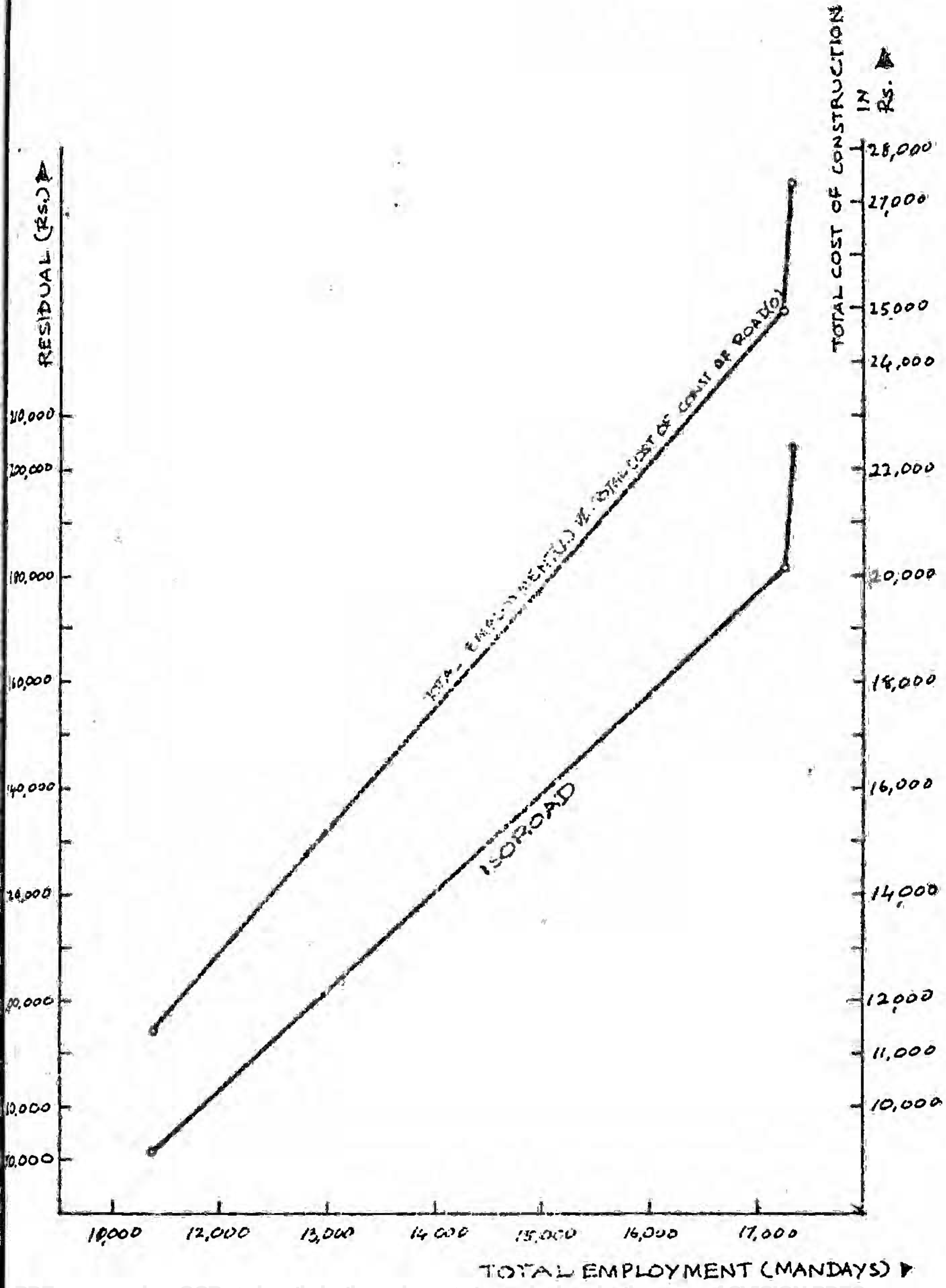

TOTAL COST OF CONSTRUCTION IN Rs.
28,000
27,000
25000
24,000
22,000
20,000
18,000
16,000
14,000
12000
11,000
10,000
RESIDUAL (Rs.)
210,000
200,000
190,000
160,000
140,000
20,000
0,000
10,000
0,000
TOTAL EMPLOYMENT(U) VS. TOTAL COST OF CONST OF ROAD(C)
ISOROAD
10,000
12,000
13,000
14,000
15,000
16,000
17,000
TOTAL EMPLOYMENT (MANDAYS)

Table 6.8.1.2

Total Employment (mandays)	Increase over the previous level (mandays)	Composite commodity or Residual (Rs.)	Increase over the previous level (Rs.)
11359.154	-	70845.38	-
17317.086	5957.932	181301.176	110455.806
17349.574	32.488	204752.47	23451 .294

Graph 6.8.1.1 shows also a plot between the level of total employment and the gross cost of road construction. Table 6.8.1.3 below shows the incidence of increasing the total employment on the cost of road-construction.

Table 6.8.1.3

Total employment (mandays)	Percentage increase over the base solution level	Cost of construction	Percentage increase over the base solution level
11359.154	-	114056.99	-
17317.086	52.45	249262.193	118.54
17349.574	52.74	273388.87	139.70

From the above table it can be concluded that elasticity of the cost of road construction with respect to total employment is more than one. The obvious conclusion from this observation is that, for a given expenditure-outlay for construction of a national highway of specified dimensions, the base solution would not only produce a road of more length but also a higher level of total employment compared to any other solution.

6.8.2 <u>Sensitivity analysis with respect to employment of the most unskilled labour:</u> The row corresponding to the most unskilled labour in the model is changed to be as follows:

$$GX - 1.0\ S_g = 0 \qquad (1)$$

where "g_j"s of G are as follows:

$$g_j = D_{1j} + N_{1j}$$

where D_{1j} and N_{1j} are the 1st rows corresponding to the most unskilled labour from D and N matrices respectively. This implies

g_j = total direct and indirect employment of the most unskilled labour required per unit operation of jth activity.

The modified objective function would be to

$$\text{Minimise} \quad \phi = C \begin{bmatrix} T \\ X \end{bmatrix} - C_{sg}\ S_g$$

where S_g denotes the total employment level of this unskilled workers; and C_{sg} is the level of subsidy per manday of this employment. For $C_{sg} = 0$, the solution corresponds to the base solution. Different values given to C_{sg} imply different subsidy levels given for the employment of this labour.

Table 6 3.2.1, presents the results obtained.

Table 6.8.2.1 *

Sensitivity Analysis with respect to credit on the most unskilled labour

i = 20% CBR=15 5% maintenance costs on asphalt roads,
Concrete roads' life= 24 years

Credit on the most unskilled labour (Rs./manday.)	0	29
Objective values in Rs. (gross cost of constn.=0)	114057	249262
Capital (K) (Rs.)	9413	46353
Labour (L) (mandays)	11359	17317
K/0 (X 10^6)	82531	185962
L/0 (X10^6)	99592	69473
K/L (X 10^5)	82869	267624
DL1 DE1/L (X 10^6)	843739	824251
Electricity (Kwh)	6	34593
Coal (tonnes)	2	180
Limestone (tonnes)	0	617
Gypsum (tonnes)	0	17
Clay (tonnes)	0	323
Water (tonnes)	0	1297
Coarsesand (m^3)	8	757
Finesand (m^3)	0	101
Quarry stone (m^3)	2557	2131
Diesel (litres)	874	117
Bitumen (tonnes)	39	0
Moorum (m^3)	213	0
Miscellaneous (Rs.)	182	62177

Table 6.8.2.1 : (cont.)

Wage bill for (DL1+IL1)	33545	49706
Residual (Rs.)	80513	199557
DL1 + IL1 (man days)	7799+1726	8440+5834
DL2 + IL2 ('')	490+ 0	911+ 22
DL3 + IL3 ('')	1137+ 3	1137+ 112
DL4 + IL4 ('')	0+ 44	111+ 296
DL5 + IL 5('')	90+ 15	174+ 163
DL6 + IL6 ('')	0+0	0+ 117
Optimal Levels of Techniques	LABEXC=17541 PREPSG=120 SOLING= 1067 WBMCDM= 533 PRCRPT= 106 SLCOAT= 106	LABEXC=17541 PREPSG=120 111SBP= 533 PUZWCT= 1689

The optimal set of production techniques change only when the subsidy is increased to Rs. 29.00 per manday. This new set remains unchanged for all the subsidy levels beyond Rs. 29.00 per manday; i.e. no amount of a raise in the subsidy level per manday of employment of the most unskilled labour can increase their employment level. The solution corresponding to the level of subsidy of Rs. 29.00 per manday i.e. the puzzolana road with a lime concrete subbase provides the maximum possible employment level of the most unskilled labour. However, it is to be noted that the share of the unskilled labour among the total employment is less in this case than that corresponding to the base solution (i.e. no subsidy). That implies the puzzolana concrete road is less-intensive of the most unskilled labour compared to the bituminous road.

From the table 6.8.2.1 it is obvious that the base solution remains optimal for the road-builder even if, not he, but the government were to pay the wage bill of the unskilled labour and he minimises only the non-labour resource-costs. The residual cost (gross cost of construction - wage bill of the most unskilled labour), is less for the base solution compared to that of the other solution.

Suppose the objective is to maximise the employment level of the unskilled labour. Let us designate two policies as follows:

Policy A : To subsidise total employment

Policy B : To subsidise the most unskilled labour.

Consider the table 6.8.2.2 prepared out of the information from the table 6.8.1.1 and 6.8.2.1.

Table 6.8.2.2

Policy A				Policy B			
DL 1 IL 1 (man-days)	Total Employment mandays	Subsidy Level (Rs.)	Total Subsidy (Rs.)	DL 1 IL 1 (man-days)	Total Employment mandays	Subsidy Level (Rs.)	Total Subsidy (Rs.)
9584.159	11359.154	0	0	9584.159	11359.154	0	0
14273.634	17317.086	23.0	398292.97	14273.634	17317.086	29.0	413935.38

From the above table it is obvious that to raise the employment of the unskilled labour to a level of 14273.634 mandays the total subsidy required under policy A is less than that under policy B. In this sense, subsidising the total employment at a lower subsidy-rate is preferable to subsidising the employment of only the unskilled labour at a higher subsidy-rate when the objective is to maximise the employment-level of the unskilled labour.

6.8.3. Sensitivity analysis with respect to the price of bitumen: We have noted that the base solution implied a bituminous (asphalt) road for the proposed national highway. The base solution corresponds to a price of Rs. 692.00 per tonne of bitumen. The objective has been to minimise the total cost of construction. The total amount of bitumen required for this road according to the base solution is 38.586 tonnes. However in view of the current international oil crisis, wide fluctuations in the price of bitumen can be expected. Hence, it is important to test the sensitivity of the base solution with respect to the price of bitumen per tonne. Various levels of price per tonne of bitumen were assumed and corresponding changes in the set of production techniques were observed. Table 6.8.3.1 presents the results obtained.

Let us look at the production techniques; only when the price is raised to Rs. 4200/- per tonne a change in the solution occurred. Now, the road is preferred to be built with puzzolana wearing coat (PUZWCT) over a lime concrete subbase (111 SBP) for minimising the total cost of the road construction. No more is the bituminous road optimal and hence the total quantity of bitumen required is nil. Lime, surkhi, stone-aggregate and capital are some of the resources substituted for bitumen.

Let us draw our attention towards the changes in the resource requirements, when the price of bitumen is increased. The following table provides some of these details;

Table 6.8.3.1 *

Sensitivity Analysis with respect to price of bitumen

i=20% CBR= 15 5% maintenance costs on asphalt roads.
Concrete roads' life = 24 years

Price of bitumen per tonne (Rs.)	292	4200
Objective value in Rs. (gross cost of constn.=0)	114057	249262
Bitumen (tonnes)	39	0
Capital (K) (Rs.)	9413	46353
Labour (L) (mandays)	11359	17317
Residual (Rs.)	87356	249262
Electricity (Kwh)	6	34593
Coal (tonnes)	2	180
Limestone (tonnes)	0	617
Gypsum (tonnes)	0	17
Clay (tonnes)	0	323
Water (tonnes)	0	1297
Coarsesand (m^3)	8	757
Finesand (m^3)	0	101
Quarry stone (m^3)	2557	2131
Moorum (m^3)	213	0
Diesel (litres)	874	117
Miscellaneous (Rs.)	182	62177
DL1 + IL1 (mandays)	1799+1786	8440+5834
DL2 + IL2 (")	490+ 0	911+ 22
DL3 + IL3 (")	1137+ 0	1137+ 112
DL4 + IL4 (")	0+ 44	111+ 296
DL5 + IL5 (")	90+ 15	174+ 163
DL6 + IL6 (")	0+0	0+ 117

Table 6.8.[illegible].1 (cont.)

ptimal Levels of echniques	LABEXC=17541	LABEXC=17541
	PREPSG=120	PREPSG=120
	SOLING= 1067	111SBP= 533
	WBMCDM= 533	PUZWCT= 1689
	PRCRPT= 106	
	SLCOAT= 106	

Table 6.8.3.2

Bitumen price (Rs/ tonne)	percent change in the price	capital (K, (Rs.)	percent change in capital	labour (L) (man-days)	percent change in L	cost of construction (Rs.)	percent change in the cost
692.00	-	9413.193	-	11359.154	-	114056.99	-
4200.00	506.94	46353.345	392.43	17317.086	52.45	249262.195	118.54

It is clear from the above table that to effect relatively a little percentage increase in the employment, the necessary percentage increase in the price of bitumen is very high. Hence, we may conclude that the price of bitumen cannot be a policy variable to effect changes in the employment levels. Another important point to be noted here is the enormous increase in the capital services required for road construction if the present international oil crisis were to increase the domestic price of bitumen to a very high level.

Let us look at the implications of the rise in the price of bitumen on the employment of the most unskilled labour. The difference between the two cases (table 6.8.3.1) as far as the most unskilled labour is concerned is 4689.459 mandays. Corresponding difference in the total employment levels is 5957.932 mandays. However, we note that the share of the unskilled labour among the total employment fell when the price of bitumen was increased. This can be understood easily because the soling, premix carpet and sealing coat activities require essentially only unskilled labour and hardly any skilled labour belonging to higher wage groups, which is not true in the case of the activities of any concrete road. So, we conclude that the hike in the price of bitumen affects the composition of the total employment adversely to the most unskilled labour.

Summarising the above discussion, a rise in the price of bitumen has very undesirable affects for the following reasons:

(i) The change in techniques brought about in response to increasing price of bitumen generates very little additional employment.

(ii) On the other hand it raises the outlay on capital expenditure for road construction.

(iii) A rise in the price adversely affects the most unskilled labour as far as the composition of the total employment is concerned.

6.8.4 <u>Sensitivity analysis with respect to nature of the soil</u>: For any road, the soil foundation receives the traffic loads, from the pavement. The subgrade is the surface of the natural ground on which the entire road structure rests. If the subgrade fails the performance of the whole road gets affected. Strength of the subgrade depends on the bearing capacity of the soil "CBR (California Bearing Ratio) is a measure of the load carrying capacity (resistance to direct penetration) of any soil or granular material which is expressed as a percentage of the load

Table 6.8.4.1

Sensitivity Analysis with Respect to CBR

i= 20%.   5 % maintenance costs on asphalt roads
Concrete roads' life = 24 years

CBR (%)	7	10	15	20
Objective values in Rs.(gross cost of constn. = 9)	135715	127052	114057	109725
Capital (K)(Rs.)	11348	10574	9413	9026
Labour(L)(mday)	12992	12339	11359	11033
K/O($X10^6$)	83617	83227	82531	82262
L/O($X10^6$)	95729	97116	99592	100548
K/L($X10^6$)	873478	856985	828688	818139
Elec.(Kwh)	6	6	6	6
Coal (tonnes)	2	2	2	2
Limestone(tonnes)	0	0	[illegible]	0
Gypsum(tonnes)	0	[illegible]	0	0
Clay (tonnes)	0	0	0	0
Water(tonnes)	0	0	0	0
Coarsesand(m^3)	8	8	8	8
Finesand (m^3)	0	0	0	0
Quarrystone(m^3)	3682	3232	2557	2332
Diesel(litre)	970	932	874	855
Bitumen(tonnes)	39	39	39	39
Moorum (m^3)	213	213	213	213
Miscellaneous(Rs)	225	207	182	174

Table 6.8.4.1 :(cont.)

L1+IL1(m.day)	8737+2297	8362+2092	7799+1786	7611+1683
L2+IL2('')	650+0	586+0	490+0	458+0
L3+IL3('')	1137+0	1137+0	1137+0	1137+0
L4+IL4('')	0+61	0+54	0+44	0+41
L5+IL5('')	90+20	90+18	90+15	90+14
L6+IL6('')	0 +0	0+0	0+0	0+0
Optimal levels of Techniques	LABEXC=17541 PREPSG=120 SOLING= 1956 WBMCDM= 533 PRCRPT= 106 SLCOAT= 106	LABEXC=17541 PREPSG=120 SOLING= 1600 WBMCDM= 533 PRCRPT= 106 SLCOAT= 106	LABEXC=17541 PREPSG=120 SOLING= 1067 WBMCDM= 533 PRCRPT= 106 SLCOAT= 106	LABEXC=17541 PREPSG=120 SOLING= 889 WBMCDM= 533 PRCRPT= 106 SLCOAT= 106

carrying capacity of a standard crushed rock specimen (which is taken as of 100 percent value) determined by a penetration test. This is an arbitrary figure: a surface having a CBR of 100 percent is one in which a load of 1360 Kg. has to be exerted to drive in a cylindrical flat plunger with a base area of 19.3 sq. cm. to a distance of 0.250 mm at the rate of penetration of 0.125 mm per minute*.

We have considered CBR to be of 15 percent for the base solution. Now our interest is to know whether the base solution remains unchanged when the nature of the soil i.e. its CBR changes. We have considered three other values of CBR for this exercise. See Appendix A.

Consider the table 6.8.4.2 on the next page. It gives the details on design thicknesses of flexible (bituminous) and rigid (concrete) pavements for various CBR percentages. These details correspond to a wheel load of 12000 lbs. The table implies the following variations in the thickness of the soling work for different CBR values

CBR	Thickness of the soling work
7	11" = 27.94 cm.
10	9" = 22.86 cm.
15	6" = 15.24 cm.
20	5" = 12.70 cm.

Table 6.8.4.2 also implies that in the case of concrete roads, nature of the soil within the range we have

---

* See Practical Civil Engineers Handbook by P.N.Kharma.

Table 6.8.4.2

Design thicknesses of flexible and rigid pavements for various CBR values

Wheel load = 12000 lb.

Subgrade CBR percent	Total thickness of flexible pavement	Thickness of concrete slab required over 3 in. WBM subbase
2	27"	10.0"
3	23"	10.0"
5	17"	9.5"
7	14"	9.5"
10	12"	9.5"
15	9"	9.5"
20	8"	9.5"
30	6"	9.0"

Note 1. The design thicknesses shown for flexible pavements are overall thicknesses and superior surfacing such as bitumious concrete form part of the design crust; but sufface dressing etc. are provided over and above.

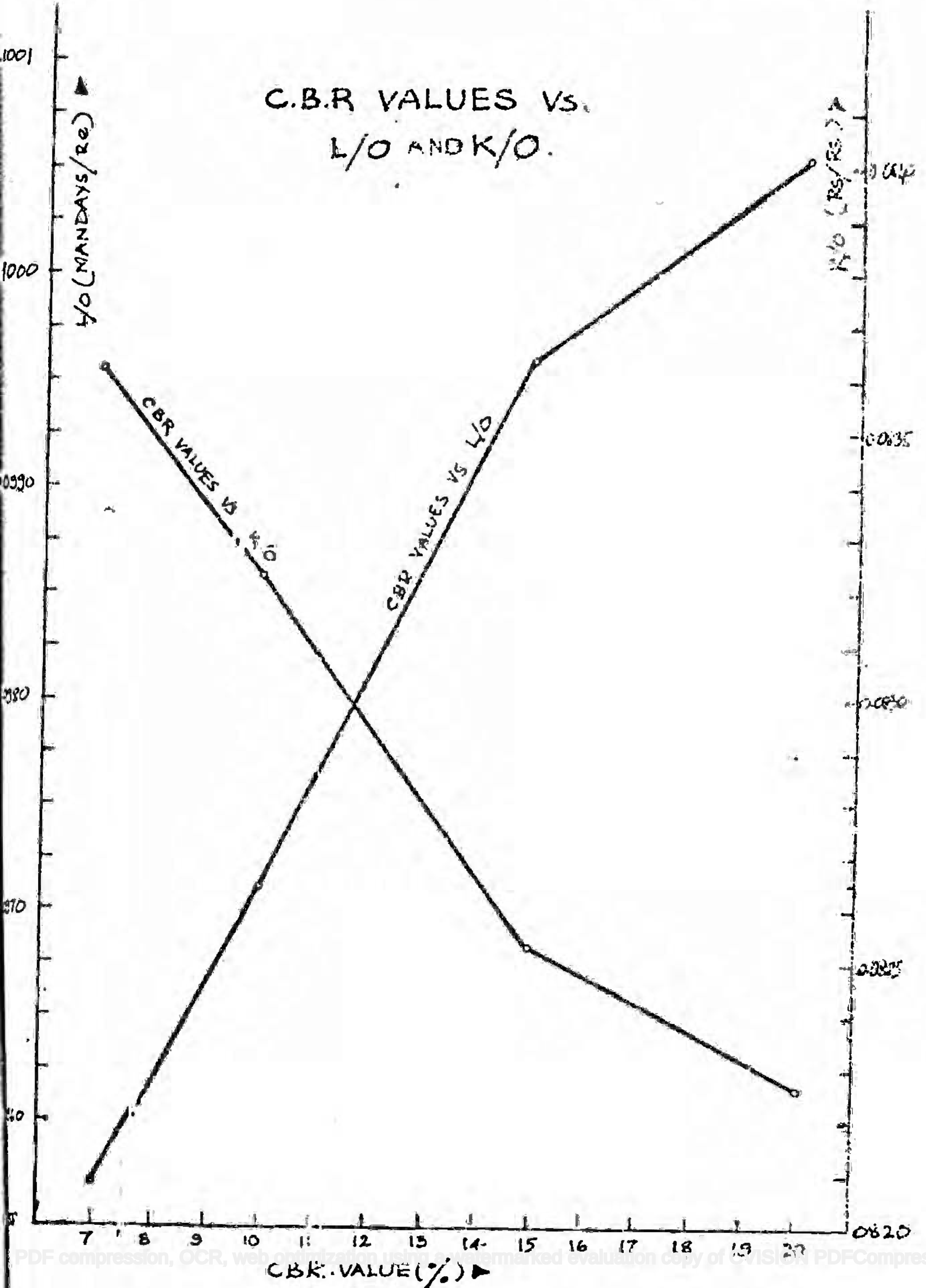
2. In case of rigid pavements, thickness of concrete slabs shown in addition to 3 in. WBM.

Source: Taken from table 1 of "Economics of Highway Payment Design" by Bh.Subba Raju and M.P.Dhir. Road Research Papers No.37. C.R.R.I., New Delhi

considered does not demand any change in crust thickness of the road. Thickness of the concrete slab is always 9.5" for CBR values of 7, 10, 15 and 20.

So, in our exercise, change of CBR implies change in output required of only soling work. We changed the output

Graph:6.8.4.1.


C.B.R VALUES VS.
L/O AND K/O.
L/O (MANDAYS/Re)
K/O (RS/RS.)
CBR VALUES VS K/O
CBR VALUES VS L/O
.1001
1000
0990
980
970
60
0.0840
0.0835
0.0830
0.0825
0820
7
8
9
10
11
12
13
14
15
16
17
18
19
20
CBR. VALUE(%)

coefficient of the soling work according to the desired CBR values. The results are tabulated in table 6.8.4.1.

We observe that the nature of the soil has no effect at all on the set of production-techniques selected. In all the cases bituminous road is preferred to a concrete road.

However, we observe the following two points from table 6.8.4.1: (i) capital expenditure per rupee cost of road construction falls as CBR value increases i.e. as the soil gets firmer. (ii) Labour per rupee cost of road construction increases as CBR value increases.

Note that the fall in the output of the soling work required is less in proportion to the increase in the CBR value (see appendix A). So, soling by itself being a labour consuming activity, the two points are easily understandable. Graph 6.8.4.1 presents these results.

6,8.5 <u>Sensitivity analysis with respect to interest rate</u>: Use of interest rate is required in calculating the rental values on capital equipment required directly or in indirectly in the road construction and also in discounting all the future costs (relaying premix carpet and sealing coat for every 8 years and maintenance costs) involved in the the case of bituminous roads. The base solution corresponds to an interest rate of 20 percent. Now we would like to know whether the base solution remains unchanged if the rate of interest is varied from 20 percent to some other value.

Table 6.8.5.1 *

Sensitivity Analysis with respect to Interest Rate

CBR = 15. 5% maintenance costs on asphalt road. Concrete roads' life = 24 years

Interest Rate (i) in (%) →	5	10	15	20	25
Objective value in Rs. (gross cost of constn. =0)	144161	127290	118603	114057	111778
Capital (K) (Rs.)	6532	7262	8253	9413	10706
Labour (L) (mandays)	13244	12238	11685	11359	11155
K/O (X 10^6)	45313	57054	69586	82531	95775
L/O (X 10^6)	91869	96144	98524	99592	99797
K/L (X 10^6)	493232	593423	706287	823688	959700
Electricity (Kwh)	10	8	7	6	5
Coal (tonnes)	4	3	2	2	2
Limestone (tonnes)	0	0	0	0	0
Gypsum (tonnes)	0	0	0	0	0
Clay (tonnes)	0	0	0	0	0
Water (tonnes)	0	0	0	0	0
Corsesand (m^3)	15	11	9	8	7
Finesand (m^3)	0	0	0	0	0
Quarry stone (m^3)	2842	2690	2606	2557	2526
Diesel (litres)	1140	998	920	874	845
Bitumen (tonnes)	70	53	44	39	35
Moorum (m^3)	213	213	213	213	213
Miscellaneous (Rs.)	182	182	182	182	182

Table 6.8.5.1 : (cont.)

DL1 + IL1 (mandays)	8987+2422	8353+2082	8004+1896	7799+1786	7670+1717
DL2 + IL2 (")	517+0	502+0	495+0	490+0	487+0
DL3 + IL3 (")	1137+0	1137+0	1137+0	1137+0	1137+0
DL4 + IL4 (")	0+53	0+48	0+46	0+44	0+43
DL5 + IL5 (")	111+18	100+16	93+15	90+15	87+14
DL6 + IL6 (")	0+0	0+0	0+0	0+0	0+0
Optimal levels of Techniques	LABEXC=17541 PREPSG=120 SOLING= 1067 WBMCDM= 533 PRCRPT= 193 SLCOAT= 193	LABEXC=17541 PREPSG=120 SOLING= 1067 WBMCDM= 533 PRCRPT= 147 SLCOAT= 147	LABEXC=17541 PREPSG=120 SOLING=1067 WBMCDM= 533 PRCRPT= 121 SLOCAT= 121	LABEXC=17541 PREPSG=120 SOLING= 1067 WBMCDM= 533 PRCRPT= 106 SLCOAT= 106	LABEXC=17541 PREPSG=120 SOLING= 1067 WBMCDM= 533 PRCRPT= 97 SLCOAT= 97

We have considered the following interest rates : 5 percent, 10 percent, 15 percent, 25 percent. Results were tabulated in table 6.8.5.1.

We observe that the base solution has not changed at all for all the interest-rate variations. Lower values of capital rental (K) as the interest-rate falls merely indicate the same amount of capital equipment being valued at a lower interest rate. Further discussion of the figures in the table 6.8.5.1 is unnecessary.

6.8.6 <u>Alternative life for concrete roads</u>: All the previous exercises assume life of bituminous road and concrete roads to be of 8 and 24 years respectively. These assumptions are made by the following information available in civil engineering handbooks:

Life of bituminous grouted macadam = 8 years
Life of bituminous premix carpet = 8 to 15 years
Life of concrete roads = 25 to 40 years.

As the bituminous road is found to be optimal with the assumption of its life to be 8 years, a fortiori it will be optimal with any assumption of its life to be more than 8 years compared to concrete roads life of 24 years. However, it will not be possible to conclude so if the concrete road life is assumed to be 40 years. Hence we decided to assume that concrete road life to be 40 years,

Table 6.8.6.1 *

Sensitivity Analysis with respect to interest rate

CBR = 15 5% maintenance costs on bitumenous roads. Concrete roads' life = 40 years

Interest rate (percent)	5	10	15	20	25
Objective values in Rs. (gross cost of constn. =0)	162750	132467	120183	114579	107409
Capital (K) (Rs.)	7204	7492	8337	9446	10392
Labour (L) (mandays)	14268	12521	11771	11387	10923
K/O ($X 10^6$)	44262	56554	69368	82438	96751
L/O ($X 10^6$)	87666	94521	97940	99383	101699
K/L ($X 10^6$)	504891	598318	708268	829502	951351
Electricity (Kwh)	13	9	7	6	5
Coal (tonnes)	5	3	2	2	2
Limestone (tonnes)	0	0	0	0	0
Gypsum (tonnes)	0	0	0	0	0
Clay (tonnes)	0	0	0	0	0
Water (tonnes)	0	0	0	0	0
Coarsesand (m^3)	18	12	9	8	7
Finesand (m^3)	0	0	0	0	0
Quarry stone (m^3)	2997	2733	2619	2561	2491
Diesel (litres)	1285	1038	932	878	812
Bitumen (tonnes)	87	58	45	39	31
Morrum (m^3)	213	213	213	213	213
Miscellaneous (Rs.)	182	182	182	182	182

Table 6.8.6.1 : (cont.)

DL1 + IL1 (mandays)	9633+2767	8531+2178	8058+1925	7816+1795	7524+1639
DL2 + IL2 (")	531+0	507+0	496+0	490+0	484+0
DL3 + IL3 (")	1137+0	1137+0	1137+0	1137+0	1137+0
DL4 + IL4 (")	0+57	0+49	0+46	0+44	0+42
DL5 + IL5 (")	123+19	103+16	94+15	90+15	85+14
DL6 + IL6 (")	0+0	0+0	0+0	0+0	0+0
Optimal level of Techniques	LABEXC=17541 PREPSG=120 SOLING=1067 WBMCDM= 533 PRCRPT= 240 SLCOAT= 240	LABEXC=17541 PREPSG=120 SOLING=1067 WBMCDM= 533 PRCRPT= 160 SLCOAT= 160	LABEXC=17541 PREPSG=120 SOLING=1067 WBMCDM= 533 PRCRPT= 125 SLCOAT= 125	LABEXC=17541 PREPSG=120 SOLING=1067 WBMCDM= 533 PRCRPT= 108 SLCOAT= 108	LABEXC=17541 PREPSG=120 SOLING=1067 WBMCDM= 533 PRCRPT= 86 SLCOAT= 86

and obtain the solutions with respect to various interest rates. Table 6.8.6.1 presents the results obtained.

We observe that the set of production techniques is exactly the same as the one observed under the corresponding exercise with the assumption of 24 years life for bituminous road. However, the levels of premix carpet (PRCRPT) and sealing coat (SLCOAT) activities will be higher this time because the number of re-layings and total maintenance cost of these activities will be higher during 40 years compared to 24 years time-period.

We close the discussion of the results on this exercise by pointing out that the lower values of capital (K) (table 6.8.6.1) as the interest rate falls down merely indicate the same amount of capital equipment being valued at a lower interest rate.

6.9 Maximising employment subject to a cost constraint

Every thing of the model remains the same except that now we will

$$\text{Maximise} \quad LX$$

$$\text{Subject to} \quad C \begin{bmatrix} T \\ X \end{bmatrix} \leq \bar{C} \text{ or } (0)$$

where $\bar{C}$ = a specified level for the cost of the road construction.

In the cost minimisation exercise the base solution costs us Rs. 114056.99. So, here in the employment

Table 6.9.1*

Maximization of employment subject to a cost constraint

i = 20%. CBR = 15 5% maintenance costs on asphalt roads. Concrete roads' life = 24 years

Labour(L)(objective value) (mandays)	11359	12867	13872	16385	17319	17335	17350
Amount (O)(cost of constn.inRs)	114057	148274	171086	228114	250925	262331	273789
Capital (K) (Rs.)	9413	18762	24994	40575	46968	51179	55262
K/O ($X 10^6$)	82531	126535	146092	177873	187177	195093	202138
L/O ($X 10^6$)	99592	86778	81083	71829	69022	66079	63461
K/L ($X 10^5$)	82869	145814	180176	247634	271185	295241	318522
Electricity (Kwh)	6	8759	14591	29183	35189	39277	43241
Coal (tonnes)	2	47	77	152	181	194	206
Limestone (tonnes)	0	156	260	521	626	685	742
Gypsum (tonnes)	0	4	7	15	18	20	22
Clay (tonnes)	0	82	136	272	316	270	225
Water (tonnes)	0	328	547	1094	1320	1473	1622
Coarsesand (m^3)	8	198	324	640	757	756	754
Finesand (m^3)	0	26	43	86	101	101	101
Quarry stone (m^3)	2557	2449	2377	2198	2131	2131	2131
Diesel (litres)	874	682	555	235	117	117	117
Bitumen (tonnes)	39	29	22	6	0	0	0
Moorum (m^3)	213	159	123	33	0	0	0
Miscellaneous (Rs.)	182	15872	26331	52480	63057	69093	74944

Table 6.9.1 : (cont.)

DL1 + IL1 (mandays)	7799 +1786	7961 +2810	8069 +3493	8340 +5200	8440 +5828	8440 +5791	8440 +5757
DL2 + IL2 (")	490+0	597+6	668+9	845+19	911+22	911+22	911+22
DL3 + IL3 (")	1137+0	1137+28	1137+47	1137+94	1137+112	1137+112	1137+112
DL4 + IL4 (")	0+44	28+108	47+150	94+257	111+300	111 +322	111+343
DL5 + IL5 (")	90+15	111+52	125+77	161+140	174+165	174+181	174+195
DL6 + IL6 (")	0+0	0+30	0+49	0+99	0+119	0+133	0+147
Optimal levels of Techniques	LABEXC =17541 PREPSG =120 SOLING =1067 WBMCDM =533 PRCRPT =106 SLCOAT =106	LABEXC =17541 PREPSG =120 SOLING =797 WBMCDM =398 PRCRPT =79 SLCOAT =79 111SBP =135 PUZWCT =428	LABEXC =17541 PREPSG =120 SOLING =617 WBMCDM =308 PRCRPT =62 SLCOAT =62 111SBP =223 PUZWCT =713	LABEXC =17541 PREPSG =120 SOLING =167 WBMCDM =83 PRCRPT =17 SLCOAT =17 111SBP =450 PUZWCT =1425	LABEXC =17541 PREPSG =120 111SBP =497 PUZWCT =1573 111SBC =37 124WCT =116	LABEXC =17541 PREPSG =120 111SBP =244 PUZWCT =774 111SBC =289 124WCT =915	LABEXC =17541 PREPSG =120 111SBC =533 124WCT =1689

maximisation exercise, we have taken $\bar{C} = 114056.99$ for obtaining the initial solution. Then onwards $\bar{C}$ is raised gradually. The results are tabulated in table 6.9.1.

The base solution under this exercise is exactly the same as the one in the cost-minimisation exercise. Let us observe the values of the labour per rupee value of the cost of construction from table 6.9.1. We find that L/O falls gradually as the cost-outlay for construction is increased. It is therefore, clear that the base solution is again preferred to other types of the roads even if the labour per rupee value of the cost of construction is to be maximum.

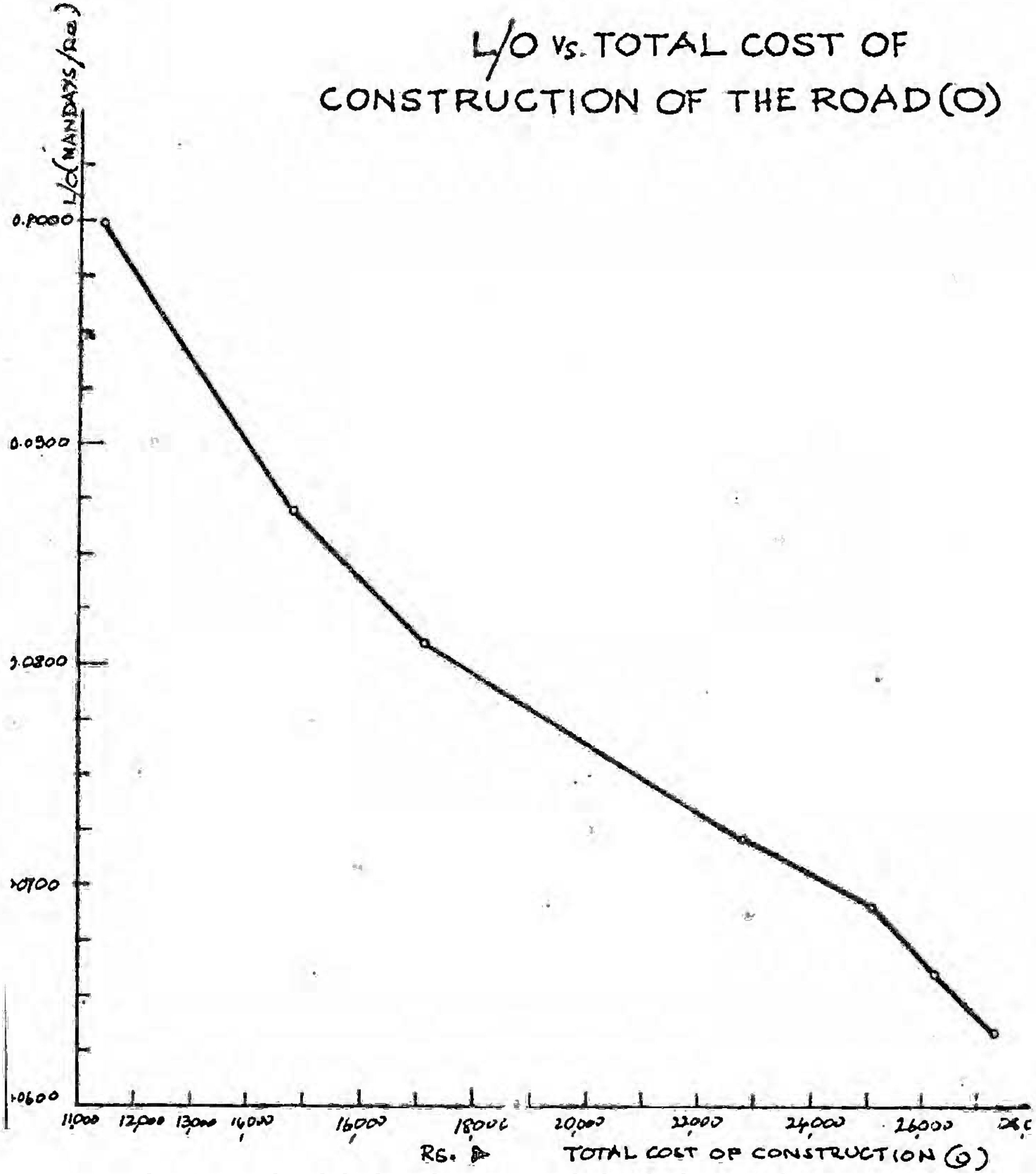
Graph 6.9.1 illustrates the relation between L/O and O and graph 6.9.2 that between the total employment (L) and the cost of construction (O). Table 6.9.2 also provides the details of the relation between L and O.

Table 6.9.2

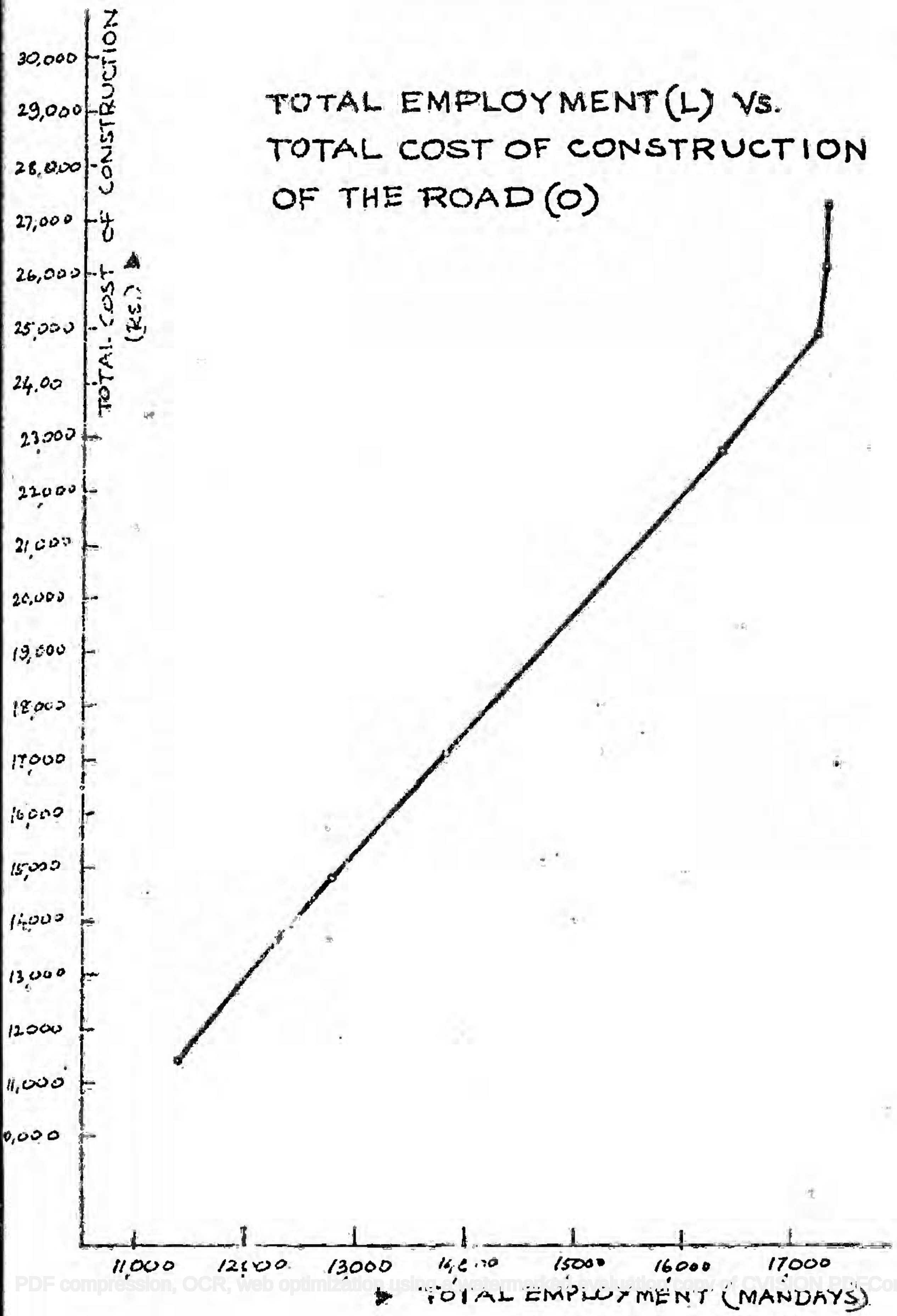
Cost of Construction (Rs.)	Percent increase over the base solution level	Employment total (mandays)	Percent increase over the base solution level
114057.00	–	11359.154	–
148274.10	30	12866.96	13.274
171085.50	50	13872.164	22.123
228114.0	100	16385.173	44.246
250925.40	120	17319.326	52.47
262331.10	130	17334.684	52.605
273388.83	139.7	17349.574	52.737

Graph: 6.9.1.

L/O Vs. TOTAL COST OF CONSTRUCTION OF THE ROAD (O)



Graph: 6.9.2.



TOTAL EMPLOYMENT (L) VS. TOTAL COST OF CONSTRUCTION OF THE ROAD (O)

From the above table it is clear that the elasticity of the cost of road construction with respect to the total employment is more than one, a point which has been already learnt in a previous exercise.

6.10 Conclusion for Road Construction

In this section we summarise some of the important conclusions drawn from all the previous exercises on road construction.

Asphalt roads are preferred to concrete roads for building the national highways. According to the base solution the costs on labour and materials amount to more than one-third and half respectively of the total cost of road-construction. Rental values on capital equipment, direct and indirect together account for only less than 10 percent of the total cost. Around 16 percent of the total employment generated by road construction is indirect. Labour of the lowest wage-group forms major part of the total employment (85 percent of the total). Share of this labour is very high in both direct and indirect employment-totals separately.

It is observed that by changing the type of road to be built for national highways the levels of total employment and employment of the most unskilled labour can be increased. To compensate the additional cost of construction involved in selecting a different type of road from the one corresponding to the base solution, suitable economic policies may have to be devised. However, the elasticity of road construction with respect to the total employment is more than one. It is also to be noted that the techniques of higher employment potential are less intensive towards the most unskilled labour.

The solution which minimises the gross cost of construction minimises also the cost of non-labour resources and the wage bill separately.

Puzzolana concrete road is preferred to asphalt road if the price of bitumen is increased to Rs. 4200.00 per tonne. Such a variation in the bitumen-price increases the level of total employment. However the price of bitumen should not be a policy variable for increasing the employment level because to effect relatively a little percentage increase in the employment, the necessary percentage increase in the price of bitumen is very high. Besides an increase in the bitumen-price raises the outlay on capital expenditure for road construction and also affects the most unskilled labour as far as the composition of the total employment is concerned.

Asphalt road is preferred to a concrete road for all natures of the soil. The base solution is insensitive over the range of interest rates also that is considered. No concrete road is preferred even if its life time is 40 years compared to 8 years life time of an asphalt road. Asphalt road is preferred to other types of roads even if the labour per rupee value of the cost of road construction is to be maximum.

Appendix A

ENGINEERING DESIGN AND DERIVATION OF OUTPUT AND TECHNICAL CONSTRAINTS

A.I. Building Construction

In this section of the appendix, the civil engineering design of the specified single storey-house of this project work is presented. Plan and elevation details of the house are shown in plates 1 and 2. The roof, load bearing walls partition walls, foundation and foundation-bed below the walls, flooring and plastering, external as well as internal are the different stages of construction of this house. Only the calculations with a brief description of principles of the design are presented here. For a detailed discussion of the theory of the design, standard textbooks on building construction in civil engineering may be consulted. We take up different stages of the construction in the following order:

(1) Roof

(2) Load bearing walls (brick walls, stone walls precast block walls):

- (a) Superstructure
- (b) Foundation
- (c) Foundation Bed.

(3) Partition walls (brick walls, precast block walls):

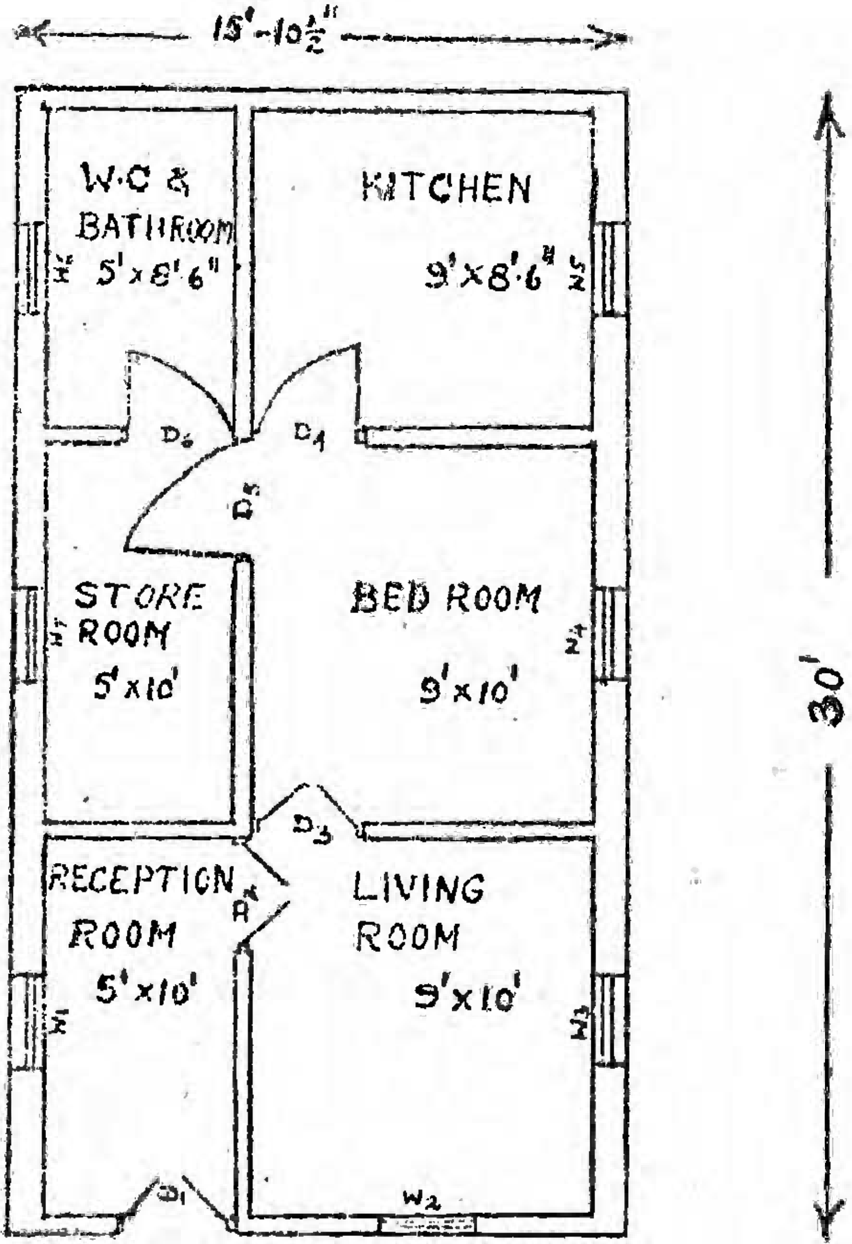
- (a) Superstructure
- (b) Foundation
- (c) Foundation Bed

(4) Flooring

(5) Plastering:

- (a) external and
- (b) internal.

PLATE 1.

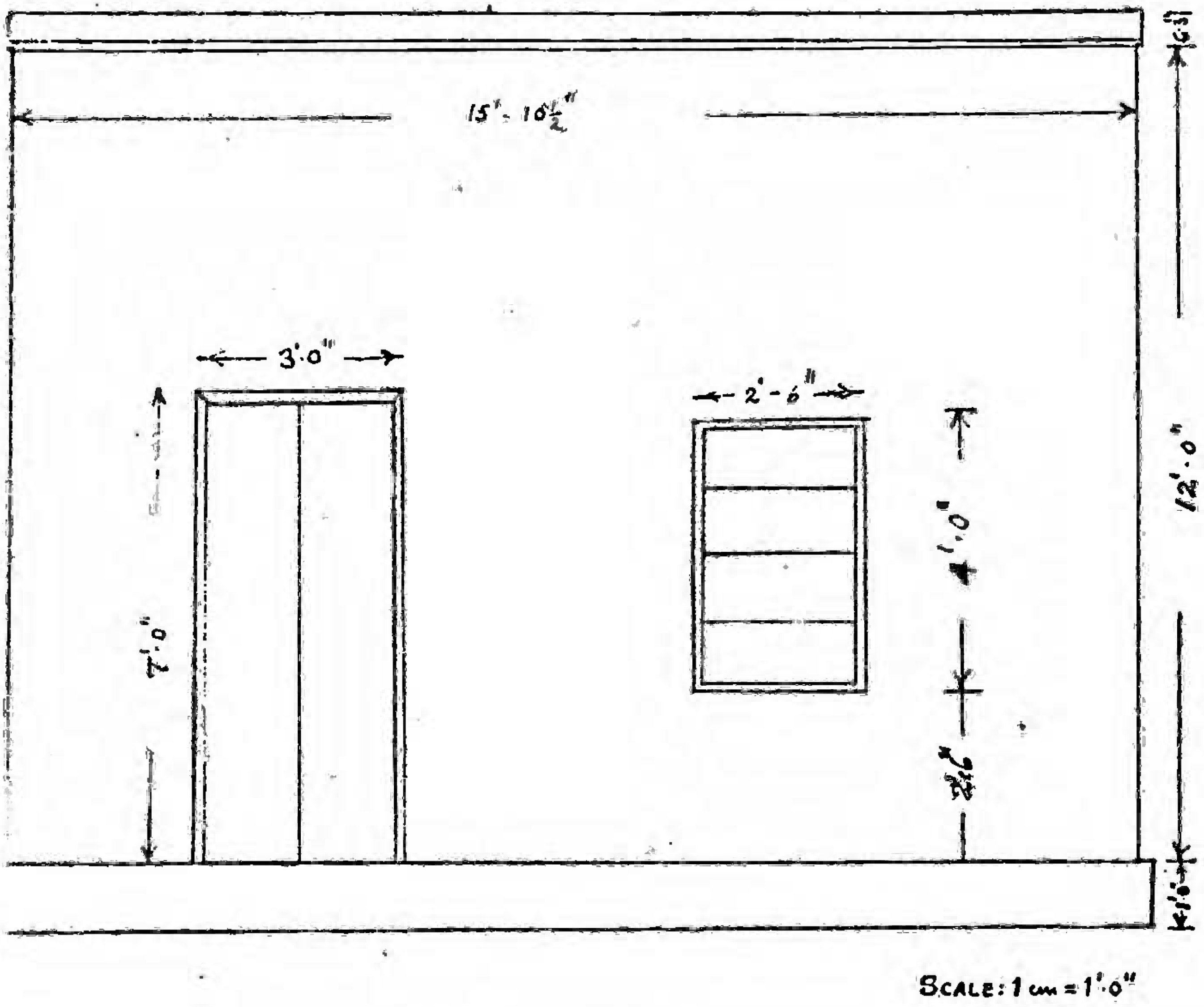


SCALE: 1cm = 2'-0"

PLAN

Wi : WINDOW-OPENING : 2'6"x4'0".
Di : DOOR-OPENING: 3'0"x7'0".
MEASUREMENTS USED FOR
DRAWING PLATES 1 AND 2
CORRESPOND TO THE BASE
[illegible]

PLATE 2.



ELEVATION

4.1.1. Roof Design

Principles involved in the design of roof

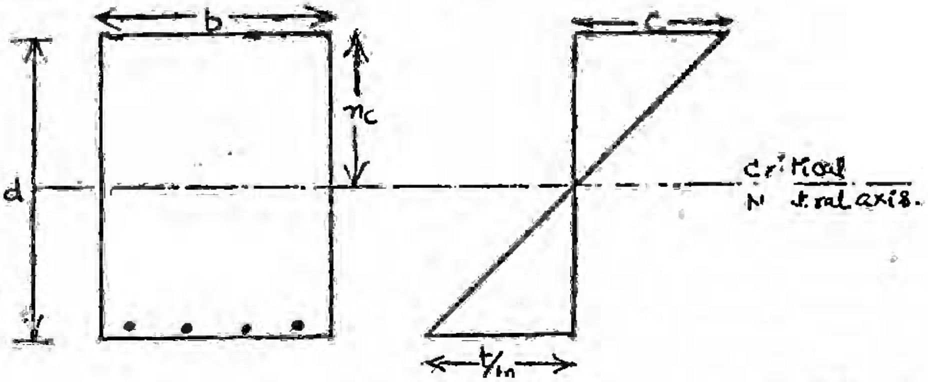
$m = \frac{2800}{3\ c}$ = modular ratio.

c = maximum permissible compressive stress due to bending in concrete, in Kg/cm^2.

t = allowable tensile stress of steel used, in Kg/cm^2.

(a) Critical or Balanced Section:

When the maximum stresses in steel and concrete simultaneously reach allowable values the section is called balanced or critical section.



Depth of neutral axis, $n_c = \frac{1}{1 + \frac{t}{c.m}} \times d = \frac{mc}{mc + t}\, d = n_1.d$

where $$n_1 = \frac{mc}{mc + t}$$

Values of 'm' for different concrete-mixes are such that the product of m and c is a constant. Hence, for a particular grade of steel (i.e. for a particular value of t), $\frac{t}{mc}$ is a constant. So n_1 is same for all mixes.

Total compressive force $= b \times n_c \times \frac{c}{2}$

Total tensile force $= t \times A_t$

$$\text{Lever arm} = a = d - \frac{n_c}{3} = d - \frac{n_1 d}{3}$$

$$= \left(1 - \frac{n_1}{3}\right) d = a_1 d$$

where $a_1 = 1 - \frac{n_1}{3}$

'a_1' is called lever-arm constant for balanced section; and is same for all mixes.

$$\text{Moment of Resistance} = R = b \times n_c \times \frac{c}{2} \times \left(d - \frac{n_c}{3}\right)$$

$$= \frac{1}{2}\, c . n_1 . a_1 . bd^2$$

'$\frac{1}{2}\, c . n_1\ a_1$' is constant for particular values of allowable stresses and is denoted by Q

$\therefore$ $R = Qbd^2$ where $Q = \frac{1}{2}\, n_1\ c\ a_1$

or $= t\ A_t\ a_1\ d$ where $A_t = \frac{R}{t\ a_1\ d}$

Design: To design a beam or a roof to resist a given bending moment. Here design is worked out as a balanced section.

(i) Work out the constants; n_1 a_1 and Q for given allowable stresses.

(ii) From the equation,

$$\text{Bending Moment} = M = \text{Moment of Resistance} = R$$
$$= Q\, bd^2$$

depth of the roof 'd' is calculated.

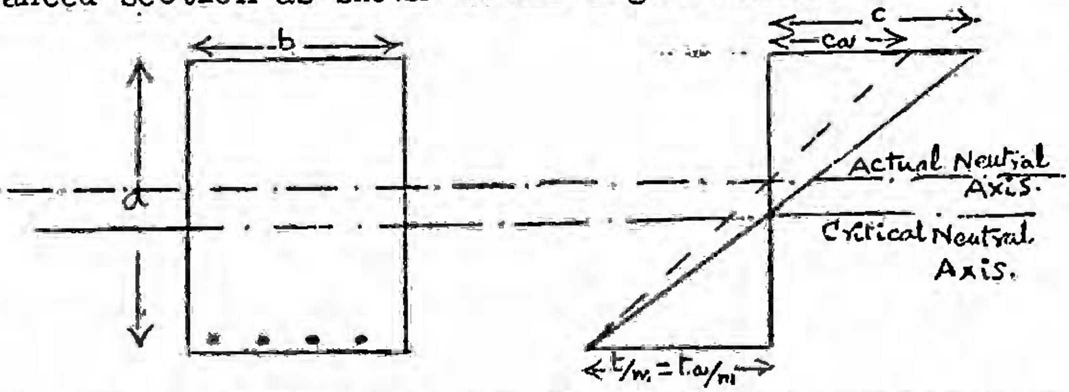
(iii) Calculate the amount of steel (tensile) from equation:

$$A_t = \frac{R}{t . a_1 . d}$$

(iv) Adequate cover is provided to tensile steel and overall depth 'D' of the beam is fixed.

(b) Under-reinforced Section:

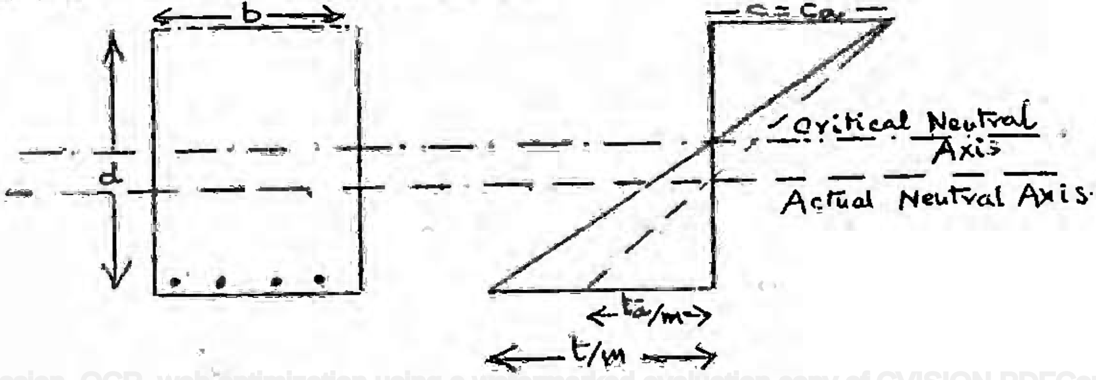
When the percentage of steel in a section is less than that required for a balanced section, the section is called ".under reinforced" section. In this case concrete stress does not reach the maximum allowable value. The depth of neutral axis (n.a.) is smaller than that in the balanced section as shown in the figure below:



The moment of resistance of such a section is governed by allowable tensile stress in steel.

(c). Over-reinforced Section:

When the percentage of steel in a section is more than that required for a balanced section, the section is called "over-reinforced" section. In this case steel stress will not reach maximum value. The neutral axis depth will be greater than that in the balanced section as shown in the figure below:



The moment of resistance of such a section will be governed by allowable compressive stress in concrete.

<u>Cases(b)and(c) together explore the substitution possibilities between steel and concrete.</u>

<u>Design</u>: Given the dimensions of the section of a beam or a roof and bending moment to be resisted and maximum allowable stresses, problem here is to design the area of tensile reinforcement.

(1) For the given stresses determine the constants r_1, n_1 and Q;

(2) For the given dimensions of the section, find the moment of resistance of critical section $R = Q\,bd^2$.

(3) (a) If the actual B.M. is less than the moment of resistance R of critical section, the section is to be designed as an under-reinforced one.

$$M.R. = t.\,A_t\left(d - \frac{n}{3}\right)$$

Taking moments about, neutral axis

$$b.n.\frac{n}{2} = m\,.\,A_t\,(d-n), \quad \text{and}$$

$$A_t = \frac{b.n^2}{2m\,(d-n)}$$

$$\text{So } M.R. = \frac{t.\,bn^2}{2m(d-n)}\left(d - \frac{n}{3}\right) = B.M. \qquad (i)$$

(i) is to be solved for n. Then A_t gives reinforcement values.

(b) If the actual B.M. is more than the moment of resistance of critical section, the section is to be designed as over-reinforced.

$$M.R. = b.n.\frac{c}{2}\left(d - \frac{n}{3}\right)$$

From this equation value of n can be solved. Area of steel can be obtained from the equation

$$b.n.\frac{n}{2} = m.A_t.\,(d-n) \quad \text{(taking moments about neutral axis)}$$

Calculations:

Total load of roof slab = Dead load+Live load

Span of the roof = 15' = 4.572 m.
R.C.C.Weight = 135 lb./cft.
Brickwork weight = 120 lb/cft.
Live load = 25 lb./sq.ft. for single storey houses.

(a) Reinforced cement concrete roof (R.C.C. roof)

Roof is assumed to be 5" thick for the sake of load calculations

$$\text{Dead load : } 15' \text{x} \left(\frac{5}{12}\right)' \text{x } 1' \text{ x } \left(135\ \frac{\text{lb.}}{\text{cft.}}\right) = 843.615 \text{ lb.}$$

$$\text{Live load : } 15'\text{x}1'\text{x}\left(25\ \frac{\text{lb.}}{\text{sq.ft.}}\right) = 375.00 \text{ lb}$$

$$\underline{}\; 1218.615 \text{ lb/ft.run}$$

Total load per metre run (b=1 m) = 1218.615x 3.28
= 3997.0572 lb.
= 4000 lb.(say)
= 1814.4 Kg/metre run

(b) Reinforced brick roof:

Roof is assumed to be 6" thick for the sake of load calculations.

$$\text{Dead load: } 15'\text{x}\left(\frac{6}{12}\right)' \text{x } 1'\text{x}\left(120\ \frac{\text{lb.}}{\text{cft.}}\right) = 900.00 \text{ lb}$$

$$\text{Live load: } 15'\text{x}1'\text{x}\left(25\ \frac{\text{lb.}}{\text{sq.ft.}}\right) = 375.00 \text{ lb}$$

$$\underline{}\; 1275.00 \text{ lb/ft.run}$$

Total load per metre run (=1 m) = 1275.0 x 3.28
= 4182.00 lb
= 4400.00 lb(say)
= 1994.4 Kg/metre run

Calculations of bending moment:

(a) R.C.C. roofs : Total load acting on the span of 15' (or 4.572 m) of the slab = 4000 lbs.= 1814.4 Kg.=W

w = load per centimetre run of the slab

$= \frac{W}{l}$, where l = span = 4.572 m.

$= \frac{1814.4}{457.2} = 3.9686$ Kg./cm.

M = Bending Moment = $\frac{w.l^2}{8}$

$= \frac{3.9686}{8} \times (4.572)^2 \times 10^4$

= 103692 Kg. cm.

(b) Reinforced brick roof: Total load over 4.572 m-span of the roof = 4400 lbs.= 1994.4 Kg. = W

w = load per centimetre run of the slab

= W/l where l = span = 4.572 m

= 1994.4/ 457.2 = 4.3654 Kg./cm.

M = Bending Moment = $\frac{w.l^2}{8}$

$= \frac{4.3654}{8} \times (4.572)^2 \times 10^4$

= 114060.00 Kg.cm.

Thickness of the slab:

(a) Balanced designs.

(i) 1:1:2.R.C.C.: Q = 14.96, b = 100 cm., M = 103692

$d = \sqrt{M/Qb} = \sqrt{103692/1496} = 8.4$ cm.

(ii) $1:1\frac{1}{2}:3$ R.C.C.: Q = 12.36, b = 100 cm., M = 103692

$d = \sqrt{103692/1236} = 9.2$ cm.

(iii) 1:2:4 R.C.C. : Q = 9.76, b = 100 cm., M = 103692

$d = \sqrt{103692/976} = 10.4$ cm.

(iv) Reinforced brick roofs

Q = 5.45, b = 100 cm., M = 114060

$d = \sqrt{114060/545} = 14.5$ cm.

(v) 1:3:6 R.C.C. Q = 5.47, b = 100 cm, M = 103692

$d = \sqrt{103692/547} = 13.8$ cm.

(b) Substitution possibilities between steel and concrete:

We confine this analysis to only 1:2:4 concrete mix for which

$c = 52.73\ \text{Kg/cm}^2$, $m = 17.8$, $n_1 = 0.4259$

$a_1 = 0.8580$, $Q = 9.76$ and for steel of

$t = 1265\ \text{Kg/cm}^2$.

Note that in the case of corresponding (i.e. 1:2:4 mix) balanced design

$d = 10.4$ cm. and $M = 103692$ Kg./cm.

(b1) Under reinforced design calculations:

Let 'd' be fixed at 13 cm. so that

D = overall depth $= d+2 = 13+2 = 15$ cm.

$Qbd^2 = 9.76 \times 100 \times 169 = 164944 > 103692$

(i.e. Bending Moment (M) < Moment of Resistance(R)

So the section has to be designed as under reinforced.

$$M = 103692 = R = \frac{t.bn^2}{2m\ (d-n)}\ (d - n/3)$$

$$103692 = \frac{1265 \times 100.\ n^2}{2.(17.8)(13-n)}\ (13-n/3)$$

$$103692(13-n) = 1184.893(39-n)\ n^2$$

$$n^3 - 39\ n^2 - 87.512\ n + 1137.66 = 0$$

Solving for n, $n = 4.62$ (approx.) cm,

$\therefore$ Area of reinforcement

$$A_t = \frac{bn^2}{2m(d-n)} = \frac{100\ (21.3444)}{35.6(8.38}$$

$= 7.15$ Sq.cm.

Weight of Steel $= 0.0715 \times 78.30$*

$= 5.60$ Kg./Sq.m. of slab

---

* Steel weight $= 7830\ \text{Kg./m}^3$

(b2) Over-reinforced calculations: Let d be fixed at 9 cm.

so that $D = d+2 = 9+2 = 11$ cm.

$$Qbd^2 = 9.76 \times 100 \times 81 = 79056 < 103692$$

(i.e. Bending Moment (M) > Moment of Resistance ($\bar{R}$)

So the section has to be designed as overinforced.

Equate bending moment to actual moment of resistance.

$$103692 = 100\, n \,.\, \frac{52.73}{2}\,(9-n/3) = b.n.\frac{c}{2}(d-n/3)$$

Simplifying, we get

$$n^2 - 27\, n + 117.99 = 0.$$

Solve for n;

$$\text{(i.e) } n = \frac{\pm 27 \pm \sqrt{(27)^2 - 4.(117.99)}}{2}$$

$$= \frac{43.05}{2} \text{ or } \frac{10.95}{2}$$

= 21.525 cm. or 5.475 cm, of which relevant n = 5.48 cm.

∴ Area of steel reinforcement:

$$A_t = \frac{bn^2}{2m\,(d-n)} = \frac{100.(30.03)}{35.6(9-5.48)}$$

$$= 23.97 \text{ Sq.cm.}$$

Weight of steel= 0.24 x 78.30 = 18.79 Kg./Sq.m. of slab.

Calculations of steel in balanced designs:

Area of steel reinforcement is given by

$$A_t = \frac{M}{a_1 . d . t} \quad \text{where}$$

M = Bending moment = 103692 Kg.cm.,

$a_1 = 0.858$, $t = 1265$ Kg/cm^2.

Steel weight = 7830 Kg./m^3

(i) 1:1:2 R.C.C.: $d = 8.4$ cm.

$$A_t = \frac{103692}{0.858 \times 8.4 \times 1265} = 11.37 \text{ sq.cm.}$$

$$= 0.001137 \ m^2$$

$\therefore$ Per metre run of the slab,

steel amount $= 0.001137 \ m^3$

Weight of steel $= W_t = 0.1137 \times \frac{7830}{100}$

$= 8.90$ Kg/m^2 of the slab.

(ii) 1:$1\frac{1}{2}$:3 R.C.C.: $d = 9.2$ cm.

$$A_t = \frac{103692}{0.858 \times 9.2 \times 1265} = 10.38 \text{ sq.cm.}$$

$W_t = 0.1038 \times 78.30 = 8.13$ Kg/sq.m. of the slab

(iii) 1:2:4 R.C.C.: $d = 10.4$ cm.

$$A_t = \frac{103692}{0.858 \times 10.4 \times 1265} = 9.19 \text{ sq.cm.}$$

$W_t = 0.0919 \times 78.30 = 7.20$ Kg/sq.m. of the slab

(iv) Reinforced brick roof: $d = 14.5$ cm.

$M = 114060$ Kg cm*, $a_1 = 0.8215$*

$$A_t = \frac{114060}{0.8215 \times 14.5 \times 1265} = 7.57 \text{ sq.cm.}$$

$W_t = 0.0757 \times 78.30 = 5.93$ Kg/sq.m. of the slab

(v) 1:3:6 R.C.C.: $d = 13.8$ cm.

$$A_t = \frac{103692}{0.858 \times 13.8 \times 1265} = 6.92 \text{ sq.cm.}$$

$W_t = 0.0692 \times 78.30 = 5.42$ Kg/sq.m. of the slab

---

* Note that in the case (iv) value of M and a_1 are different from those of other cases.

Table A.1.1
Final dimensional summary of various alternative roofs

Type	Overall depth D D=d+cover	Steel (Kg) per sq.m of the slab	R.C.C. per sq.m.	Code
1:2:4 R.C.C. Balanced	13 cm	7.20 Kg.	0.13 cu.m.	124 BRF or X_{67}
1:2:4 R.C.C. over reinforced	11 cm	18.79 Kg.	0.11 cu.m.	124 ORF or X_{72}
1:2:4 R.C.C. under reinforced	15 cm	5.60 Kg.	0.15 cu.m.	124 URF or X_{70}
1:3:6 R.C.C. Balanced	16.0 cm	5.42 Kg.	0.16 cu.m.	136 BRF or X_{73}
$1:1\frac{1}{2}:3$ R.C.C. Balanced	11.5 cm.	8.13 Kg.	0.115 cu.m.	115 BR or X_{68}
1:1:2 R.C.C. Balanced	10.5 cm.	8.90 Kg.	0.105 cu.m.	112 BRF or X_{69}
Reinforced Brick	16.5 cm	5.93 Kg.	0.165 cu.m.	RBROOF or X_{71}

Output Constraint:

Total required area of the roof is 30'x15' = 450 sq.ft. = 41.82 sq.mt. Then the output contraint can be written as

$$X_{67}+X_{68}+X_{69}+X_{70}+X_{71}+X_{72}+X_{73} = 41.82 \qquad (1)$$

where X_j are specified in terms of square metres.

A.1.1(a) Load Bearing Walls

The following table presents the details of various alternatives available in brick, stone and precast-block masonry for building superstructure walls and foundation below them. The table presents also the details of safe permissible loads of various works and the codes alloted to them.

Table A.1.2.1

Type of work	Safe permissible load in lbs.per sq.inch (ps.i)	Superstructure		Foundation and Basement	
		Code 1	Code 2	Code 1	Code 2
1. 1:3(cement:coarse sand)Brick work	140.00	13 CBLW	X_{37}	13 CBFL	X_7
2. 1:2(cement:coarse sand) Brick work	134.40	12 CBLW	X_{38}	12 CBFL	X_8
3. 1:4(cement:coarse sand) Brick work	124.40	14 CBLW	X_{39}	14 CBFL	X_9
4. 1:6(cement:coarsesand) Brick work	78.00	16 CBLW	X_{40}	16 CBFL	X_{10}
5. 1:1:6(cement:lime:sand) Brick work	134.40	116 BLW	X_{41}	116. BFL	X_{11}
6. 1:2:9(cement:lime:sand) Brick work	124.60	129 BLW	X_{42}	129 BFL	X_{12}
7. 1:1:8(cement:lime:sand) Brick work	128.80	118 BLW	X_{43}	118 BFL	X_{13}
8. 1:1:7(cement:lime:sand) Brick work	121.80	113 BLW	X_{44}	113 BFL	X_{14}
9. 1:1:1(Lime:surkhi:sand) Brick work	63.59	111 BLW	X_{45}	111 BFL	X_{15}
10. 1:2(lime:surkhi) Brick work	63.59	12 LBLW	X_4	12 LBFL	X_{16}
11. 1:4(cement:sand) coursed stone work	155.00	14 CCLW	X_{47}	14 CCFL	X_{17}
12. 1:6(cement:sand) coursed stone work	78.00	16 CCLW	X_{48}	16 CCFL	X_{18}
13. 1:4(cement:sand) Random stone work	125.00	14 CRLW	X_{49}	14 CRFL	X_{19}

14.1:6(cement:sand) Random stone work	62.15	16 CRLW X_{50}	16 CRFL X_{20}
15.1:1:1(Lime:surkhi: sand) course stone work	70.00	111 CLW X_{51}	111 CFL X_{21}
16.1:1:8(cement:lime:sand) coursed stone work	70.00	118 CLW X_{52}	118 CFL X_{22}
17.1:1:1(lime:surkhi:sand) Random stone work	46.66	111 RLW X_{53}	111 RFL X_{23}
18.1:1:8(cement:lime:sand) Random stone work	46.66	118 RLW X_{54}	118 RFL X_{24}
19.Precast block work		PCHBLW X_{55}	PCHBFL X_{25}

Note: X_js are specified in volume (cubic metres). For the inclusion of the above alternatives in the model the following points are paid attention to:

(i) Mortars : techniques corresponding to cement, lime-cement, and lime-surkhi composite mortars are included.

(ii) Type of masonary : (a) ordinary brick masonry is selected

(b) in stone masonary, techniques corresponding to random stone and coursed stone works are selected.

(c) techniques corresponding to precast block masonry are included.

Code (1) is used in computer work.

Code (2) is used in paper work on the next few pages.

Thus all the techniques commonly employed for building the superstructure walls and foundation works are included in this project.

Measurements of various rooms in the house are as follows:

Reception room = 5'x 10' = 50 Sq.ft.

Living room = 9'x 10' = 90 sq.ft.

Bed Room = 9'x 10' = 90 sq.ft.

Kitchen = 9'x 8.5' = 76.5 sq.ft.

Store room = 5'x 10' = 50 sq.ft.

Water closet/
Bathroom = 5'x 8.5' = 42.5 sq.ft.

Total carpet area of the house = 399 sq.ft.

There are seven (7) windows and six (6) doorts in total.

Window is of 4'0" x 2'.6" = 10 sq.ft.

Door is of 7'.0" x 3'.0" = 21 sq.ft.

There are six windows in load bearing walls and 1 window and 6 doors in partition walls. Brick-built load bearing walls are 3/4' wide whereas stone-built and precast-block-built ones are 1' and 8" wise respectively (Design can be seen in the following pages). Brick-built partition walls are 3/8' wide whereas precast-block built ones are 4" wide.

No partition wall is built with stone masonary.

Each window in a brickwall (load-bearing) occupies 7.50 cft.(10x3/4)
Each window in a stonewall (load-bearing) occupies 10.00 cft.(10x1)
Each window Precastblock wall(load-bearing)occupies 6.67 cft.(10x2/3)
Each window in a brickwall (partition) Occupies 3.75 cft.(10x3/8)
Each window precastblock wall(partition)occupies 3.33 cft.(10x1/3)
Each door in a brick wall (partition) occupies 7.875cft.(21x3/8)
Each door Precastblock walls(partition) occupies 6.99 cft.(21x1/3)

Wall thickness: This depends on the load coming on to the walls and own self-load. Three types of loads come on to the walls, roof load, live load on the roof and parapet wall load.

(a) Roof load: Design of the different types of roofs is presented already. For the sake of load calculations we assume the roof to be 6" thick. As mentioned, we know span of the roof is 15'.0". Taking weight of roof work to be 135 lbs/cft.

Roof Load = 6" x 7.5' x 1' x(135 lbs/cft) per foot run

= (0.5)'x(7.5)'x1' x 135 = 506.25 lbs per foot run.

(b) Live load on the roof: For single storey houses, live load prescribed is 25 lbs/sq.ft. on the roof.

Live load = 7.5'x1'x25 = 187.5 lbs per foot run.

(c) Parapet load: Let us not construct any parapet wall at all. So parapet load per foot run is nil.

(d) Self load: This load is due to the load of masonry in the superstructure walls.

For brickwalls : assume 9" thick = 3/4' wide and height of

Wall = 12' and plinth level = 1'

Weight of brickwork = 120 lbs/cft.

So masonry load in the case of brick work per

foot run = 1'x3/4'x 13' x 120 lbs/cft.

= 1170 lbs.

For stone walls : Thickness of the wall is 12" = 1' assumed for the sake of load calculations

Wt. of stone masonry = 150 lbs/cft.

Height of the wall and plinth level are the same as in the case of brick walls.

So masonry load in the case of stone masonry wall

= 1'x1'x13' x 150 lbs/cft

= 1950 lbs.

<u>Load coming on to load bearing walls, per foot run:</u>

(i) Brick case:

Roof load	506.25 lbs	
Live load	187.5 lbs	
Parapet load	0.0 lbs	
self load	1170.0 lbs	
Total	1863.75 lbs	= 2000.0 lbs (say)

(ii) Stone case:

Roof load	506.25 lbs	
Live load	187.5 lbs	
Parapet load	0.0 lbs	
Self load	1950.0 lbs	
Total	2643.75 lbs	= 3000.0 lbs (say)

Wall thickness: (i) Let us consider the weakest brick technique among the brick alternatives given in table A.1.2.1. These are 111 BLW or 12 LBLW (lime-surkhi-techniques) as these have only 63.59 p.s.i. as the safe permissible load. Let us calculate the load borne by the walls of $4\frac{1}{2}$" wide, built by using these techniques. That must be

$1' \times \frac{3}{8}' \times (63.59 \text{ psi}) = 12'' \times 4.5'' \times 63.6 = 54.0 \times 63.6$

= 3434.50 lbs. per foot run

With a factor of safety 1.5, these walls must bear at least

$\frac{3434.50}{1.5}$ = 2289.6 lbs/foot run safely.

But in the case of brick-built walls the total load coming on to these walls is less than this. Besides, a $4\frac{1}{2}$" wide brick-wall built by using any other technique (i.e. which has a higher safe permissible load than that of 111 BLW or 12 LMLW) should also bear this load. However, as National Building Bye-Laws do not allow $4\frac{1}{2}$" external walls, we have to build 9" wide brick walls. So any load-bearing brick wall will be of 9" thick.

(ii) Let us consider the walls of stone-masonry. We consider again the weakest alternative among the stone masonry ones. This is 111 RLW which has only 46.6 p.s.i. as the safe permissible load. Because of practicability considerations, no stone masonry wall can be less than 12" wide. Then the safe load such a wall can bear is

1'x1'x(46.6 psi) = 12"x12"x46.6 = 6710.4 lbs per foot run.

With a factor of safety 1.5 these walls must bear at least

$$\frac{6710.4}{1.5} = 3355.2 \text{ lbs per foot run,}$$

However the actual load coming on to walls, if built by stone masonry, would only be 3000 lbs. per foot run. Hence a 12" wide wall of any stone masonry (i.e. which has a higher safe permissible load than that of 111 RLW) should also bear this load. So any load bearing stone masonry wall will be 12" wide.

(iii) Let us consider the walls of precast blocks. According to the Concrete Association of India, an 8" wide concrete hollow-block wall would satisfy the requirements (of strength as well as insulation value) for a single storeyed house. Hence the load bearing walls, if built by using precast blocks, will be 8" wide.

<u>Derivation of the output constraint:</u> Load bearing walls of the house are 60' long and 12' high.

<u>Brick case</u>	60'x3/4'x12'	= 540 cft.	
	6 windows occupy	= 45 cft	
		495 cft.	= 14.02 cu.m.
<u>Stone case</u>	60'x1'x12'	= 720 cft.	
	6 windows occupy	= 60 cft.	
		660 cft.	= 18.69 cu.m.
<u>Precast case</u>	60'x0.67'x12'	= 480 cft	
	6 windows occupy	= 40 cft	
		440 cft.	= 12.46 cu.m.

If X_{37} to X_{55} are the various alternatives available in constructing the load bearing walls-superstructure, the output constraint with reference to brick case* can be written as follows:

$$(X_{37}+\ldots+X_{46})+0.75\,(X_{47}+\ldots+X_{54})+1.125\,X_{55}=14.02 \qquad (2)$$

where X_{37} to X_{46} are brick masonry alternatives,

X_{47} to X_{54} are stone masonry alternatives,

X_{55} is precast block technique, all specified in cu.m.

<u>Verification:</u> $\frac{14.02}{0.75} = 18.69$ and $\frac{14.02}{1.125} = 12.46$.

A.1.2(b) <u>Foundation for Load bearing Walls</u>

Loads coming on to the foundation are Superstructure-load and its own dead load.

---

* This implies, brick alternatives have output coefficients equal to 'one'.

(a) Brick-masonry case: We know that the superstructure load is equal to 2000 lbs. Assuming that the load due to foundation and bed (dead load) to be 1 00 lbs around,

Total load coming on to foundation per foot length:

Superstructure load = 2000 lbs
Dead load due to foundation bed = 1000 lbs
Total load 3000 lbs

See fig. (A.1) we will have a basement wall of 9" wide. This implies that base area of the foundation bed = $(2\times\frac{3}{4}' + 1')\times 1$ = 2.5 sq.ft. We will calculate the minimum depth of foundation using

Rankine's formula

$$d = \frac{p}{\gamma_e}\left[\frac{1 - \sin\phi}{1 + \sin\phi}\right]^2$$

where p = weight of structure to be carried by foundation

γ_e = weight of earth in lbs/cft. = 100 lbs/cft. for the assumed soil.

ϕ = Angle of repose = 30° fo the assumed soil.

d = Minimum depth of foundation below ground level (in ft).

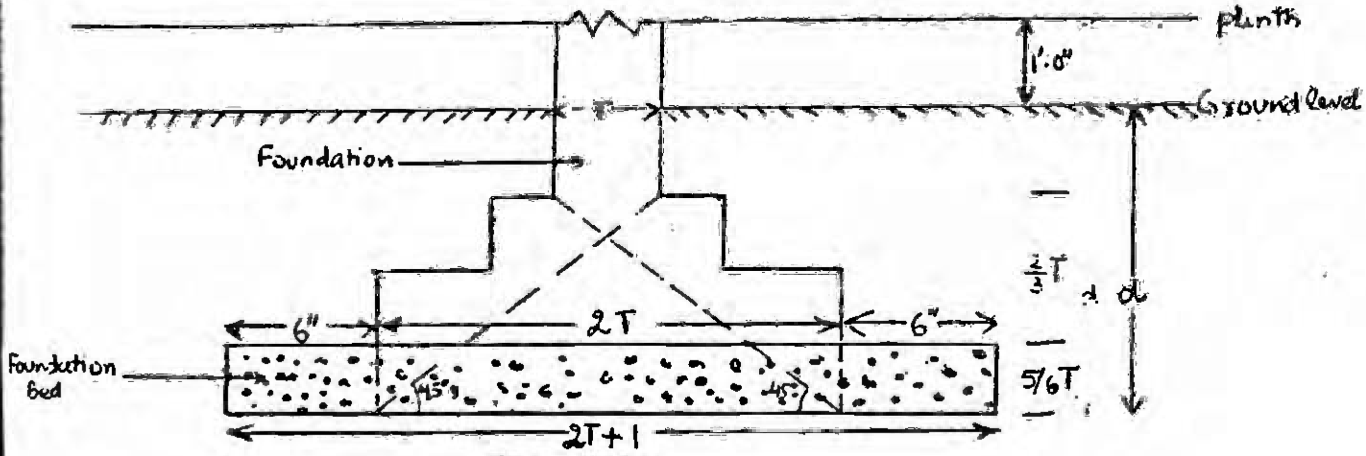


Fig (A.1)

$$p = \frac{3000}{2.5}\ , \quad \phi = 30^\circ\ , \quad We = 100$$

$$d = \frac{3000}{2.5} \times \frac{1}{100} \left(\frac{1 - 1/2}{1 + 1/2}\right)^2 = 1.33' = 1'.4''$$

Let us calculate the volume (V) of masonry in foundation and plinth per 'L' foot length for a basement wall of given thickness T'. As per fig. (A.1),

$$V = \left[(2.5-1.5T)' \times T' \times L'\right] + (2/3\ T' \times 1.75\ T' \times L)$$

$$= (2.5\ T - 1.5\ T^2)\ L + (7/6)\ T^2.L$$

$$= (2.5\ T - 1/3.T^2)\ L = T.(2.5 - T/3)L = T/3\ (7.5-T)\ L$$

or $$L = \frac{V}{(T/3)(7.5-T)}$$

Pur L = 1' } i.e. we are calculating per foot long

T = 3/4' } basement wall thickness in the case of brick masonry.

$$V = (T/3)(7.5-T)\ L = 3/4\ .\ 1/3\ (7.5-0.75) = (1/4)(6.75)$$

To construct 1' long foundation in brick masonry, 1,6875 cft. work is needed.

(b) Stone masonry case: Total load coming on to the foundation per foot length

Superstructure load	3000 lbs.
Dead load (foundation bed)	1000 lbs
	4000 lbs

The basement wall is 12" wide in this case. This implies that base area of foundation bed = (2x1'+1') = 3 sq.ft.

Applying Rankine's Formula:

$$d = \text{depth of the foundation} = \frac{4000}{3} \cdot \frac{1}{100} \times \frac{1}{9} = 1.481$$
$$= 1'.6''$$

So, we will take the depth of foundation to be 1'.6" below ground level. Structural details can be seen from fig. (4.1). Therefore volume of masonry in foundation per foot length (L=1') = V = $[(2.5-1.5T')\times T'\times 1'] + (2/3T + 1.75 \times 1)$

$$V = (T/3)(7.5-T).1.$$

Put T=1, $V = (1/3)(7.5-1) = (1/3)(6.5) = 2.167$ cft.

To construct 1' long foundation in stone masonry, 2.167 cft. work is needed.

(c) Precast-block case: Let us calculate, first, superstructure load. Weight of precast concrete-block masonry (20 cm. wide block)

for 4.0 m. height (13'.0 around), for metre run = 960 Kg.

(i.e) per foot run = $\frac{960}{3.281}$ = 2.2.6 Kg. = 650 lb (c

Roof load	506.25 lb	as calculated previously
Live load	187.50 lb	as calculated previously
Parapet load	0.0 lb	
Self load	650.0 lb	as calculated previously

Total superstructure load=1343.75 lb = 1500.0 lbs (say).

Now for foundation design; total load coming on to the foundation per foot length

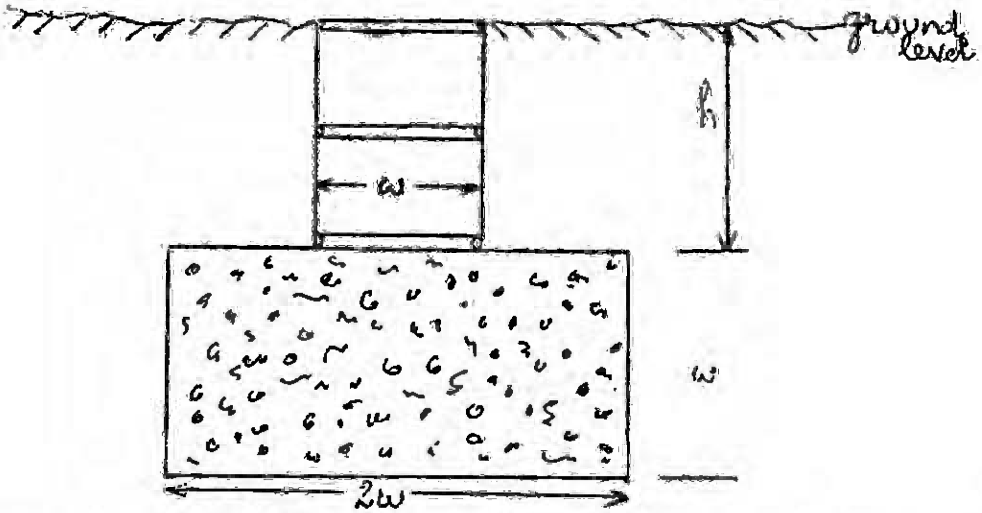
Superstructure load	1500 lb
Dead load (foundation bed)	1000 lb
	2500 lbs.

Applying Rankine's Formula

$$d = \text{depth of the foundation} = \frac{2500}{1.33} \times \frac{1}{100} \times \frac{1}{9} = \frac{25}{12} = 2'.0''.$$

Structural details of the foundation can be seen from fig. (4.2).

Fig(A·2)



w = Basement wall thickness = wall thickness = 20 cm. = 8".

Height of basement wall below ground level,

h = 2'.0"-8" = 1'.4" = 1.33'

= 16"

Plinth height = 1'.0"

Total height of foundation wall = 2.33'

Volume of foundation per foot run = 2.33'x0.67'x1

= 1.5611 cft.

To construct one foot long foundation 1.5611 cft. concrete block work is needed.

Output constraint: Load bearing walls require 60' long foundation and plinth.

(a) brick case : output required = 60'x1.6875 = 101.25 cft.
= 2.8671 cu.m.

(b) stone case : output required = 60'x2.167 = 130.0 cft.

(c) Precast case: output required = 60'x1.5611 = 93.67 cft.

Then the output constraint with reference to brick-case can be written as follows:

$$X_7 + \dots + X_{16} + 0.7788\,(X_{17} + \dots + X_{24}) + 1.0809\,X_{25} = 2.8671 \qquad (3)$$

where

X_7 to X_{16} are the alternatives in brickmasonry foundation

X_{17} to X_{24} are the alternatives in stonemasonry foundation

X_{25} is the alternative precast block foundation.

A.1.2(c) Foundation bed under load bearing walls

(a) Brick case: According to fig. (A.1), volume of foundation bed/foot length of the foundation (of which basement wall is T' wide) is

$$V = (5/6)(T)(2T+1)$$

$T=3/4' \Longrightarrow V = 5/6 \times 3/4 \times 2.50 = 1.5625$ cft.

To construct one foot long foundationbed, 1.5625 cft. concrete work is needed. Note also that to construct one foot long foundation 1.6875 cft. brick work is needed.

(b) Stone case: According to fig. (A.1), volume of foundation bed per foot length of the foundation is

$$V = (5/6)(T)(2T + 1)$$

$T=1' \Longrightarrow V = 5/6 \times 1 \times 3.0 = 2.5$ cft.

To construct one foot long foundationbed, 2.5 cft. concrete work is needed. Note also that to construct one foot long foundation 2.167 cft. stone work is needed.

(c) Precast case: According to Fig. (A.2), cross sectional area of the concrete foundationbed = 1.33'x0.67' = 0.8911 sq. ft. and hence volume of foundation bed per foot length = 0.8911 cft.

To construct one foot long foundation bed 0.8911 cft. concrete work is needed. Note also that to construct one foot long foundation, 1,5611 cft. precast block work is needed.

Output constraint : The following are the available alternatives in concrete work for the foundation bed:

1:4:8 cement concrete (X_1) 148 BFL
1:3:6 cement concrete (X_2) 136 BFL
1:2:4 cement concrete (X_3) 124 BFL

Then the output constraint can be written as follows:

$$X_1+X_2+X_3-0.926(X_7+\ldots+X_{16})-1.1537(X_{17}+\ldots+X_{24})-0.5708\ X_{25}=0 \qquad (T1)^*$$

where $\frac{1.5625}{1.6875}=0.926$, $\frac{2.5}{2.167}=1.1537$ and $\frac{0.8911}{1.5611}=0.5708$.

A.1.3 Partition Walls

A.1.3(a) Thickness of Partition Walls: Only the alternatives among brick masonry and precast block masonry are considered for partition walls. No partition wall is built with stone masonry because such walls occupy a lot of space. These walls normally can not be less than 12" wide. Note that the partition walls are 12' high, and they run for a length of 68.625' in the specified house.

(a) brick case: As the partition walls do not bear any load, these walls are built for a minimum possible width. That implies, brick-built partition walls are of $4\frac{1}{2}$" width. Load calculations are not necessary.

Total output required = 3/8'x12'x68.625' = 308.8125 cft.
= 8.75 cu.m.

---

* See page 262.

In patition walls, one window and six doors are to be built which occupy in this case 3.75 + 47.25 = 51.00 cft. Net output required is 308.8125 - 51.00 = 257.8125 cft.= 7.30 cu.m.

(b) <u>precast block-case:</u> Minimum possible width for building these walls is 4".

Total output required = 68.625'x12'x0.333' = 68.625x4

= 274.5 cft. = 7.7 cu.m.

One window and six doors occupy 45.33 cft. in this case.

Net output required = 274.50 - 45.33 = 229.167 cft.

= 6.489 cu.m.

<u>Output constraint:</u>

X_{56} to X_{65} are the alternatives in brick masonry

X_{66} is the precast block masonry technique.

The output constraint, with reference to brick case can be written as follows:

$$X_{56} + \dots + X_{65} + 1.125X_{66} = 7.30 \qquad (4)$$

where $\frac{7.30}{6.489} = 1.125.$

A.1.3 (b) <u>Foundation for partition walls:</u> The principles involved in designing the foundation and foundation bed are just the same as that for load bearing walls. Hence only the results of the design are presented below:

(a) <u>brick case:</u> Foundation details are shown in fig. (A.3). The depth of foundation of 13" below ground level is verified to be sufficient according to the Rankine's formula.

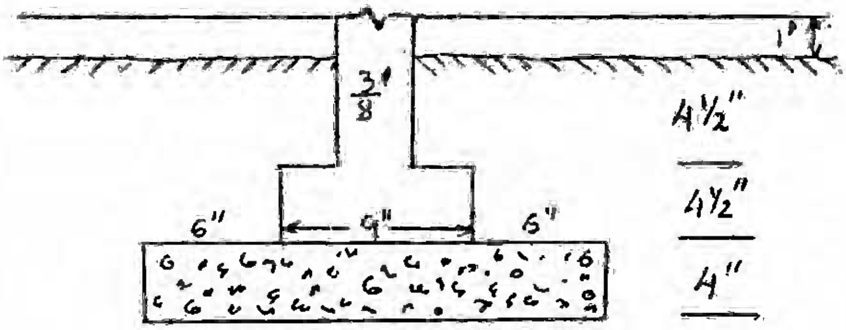


Fig (A·3)

Volume of foundation per foot length (see fig. A.3) in this case is as follows:

$$V = (\frac{3}{8} \times \frac{33}{24} \times 1) + (\frac{3}{8} \times \frac{3}{4} \times 1) = \frac{33}{64} + \frac{9}{32} = 0.7968 \text{ cft.}$$

per foot run

Total output required for 68.625'length is = 68.625'x0.7968

= 54.68 cft.

= 1.5484 cu.m.

(b) precast block case: Foundation details are shown in Fig. (A.4). The depth of foundation 12" below ground level is verified to be sufficient according to the Rankine's formula. The basement wall is kept to be 8" wide, while superstructure partition wall is 4" wide.

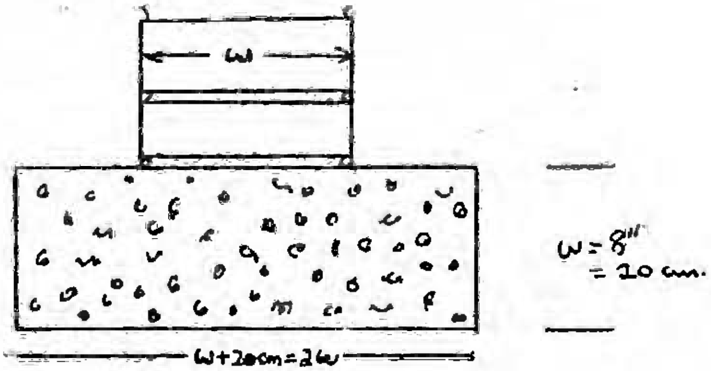


Fig (A·4)

Therefore, basement wall below ground level = 12"-8" = 4" = 0.33'
Plinth height = 1'.0 = 1.00
Total foundation height 1.33'

Thickness of the foundation wall = 8" = 0.67'

Volume of the foundation per foot run = 1.33x0.67x1 = 0.8911 cft.

Total output required for 68.625' length = 68.625x0.8911
= 61.1517 cft.
= 1.7316 cu.m.

Output constraint:

X_{26} to X_{35} are the alternatives in brick masonry.
X_{36} is the alternative of precast block masonry.

Then the output constraint, with reference to brick case can be written as follows:

$$X_{26}+\ldots+X_{35} + 0.8942\ X_{36} = 1.5484 \qquad (5)$$

where $\frac{54.68}{61.1517} = 0.8942.$

A.1.3.(c) Foundation bed under partition walls:

(a) brick case: According to fig. A.3, volume of foundation bed per foot long foundation is 21"x4"x1' = $\frac{7}{12}$ cft.
=0.5833 cft.

To construct one foot long foundation bed, 0.5833 cft. of concrete work is needed. Note also that to construct one foot long foundation for partition walls, 0.7968 cft. of brick masonry is needed.

(b) precast block case: According to Fig. A.4 volume of foundation bed per foot long foundation is wx2wx1'
= 0.67 x 1.33 x 1 = 0.8911 cft.

To construct one foot long foundation bed, 0.8911 cft. of concrete work is needed. Note also that, to construct one foot long foundation for partition walls, 0.8911 cft. of precast block work is needed.

Output constraint: The following are the available alternatives in concrete work for constructing the foundation bed : 1:4:8 cement concrete work (148 FBP or X_4), 1:3:6 cement concrete work (136 FBP or X_5), 1:2:4 cement concrete work (124 FBP or X_6). Then the output constraint can be written as follows:

$$X_4+X_5+X_6 - 0.73205(X_{26}+\ldots+X_{35})-1.0000\ X_{36} = 0 \qquad (T2')^*$$

Where

$$\frac{0.5833}{0.7968} = 0.73205 \text{ and } \frac{0.8911}{0.8911} = 1.00.$$

4.1.4 Flooring:

We have selected five different alternatives of flooring that are commonly found in housing construction. They are the following:

1) 40 mm thick 1:2:4 cement concrete flooring: 124FLG or X_{74}
2) Brick flooring in 1:4 cement mortar : 14BFLG or X_{75}
3) Brick flooring in 1:6 cement mortar : 16BFLG or X_{76}
4) Rough chiselled sandstone flooring in 1:5 cement mortar : 15RFLG or X_{77}
5) Finely dressed sandstone flooring in 1:5 cement mortar : 15FFLG or X_{78}

---

* See page 258

Output required: Total flooring area is 30'x15' = 450 sq.ft. = 41.82 sq.m. Then the output constraint can be written as

$$X_{74}+X_{75}+X_{76}+X_{77}+X_{78} = 4.182 \qquad (6)$$

where X_j, $j = 74$ to 78 are specified in the units of 10 sq.mt. each.

A.1.5 Plastering

A.1.5 (a) External plastering: Usually cement mortar or cement-lime composite mortar is used for external plastering. We have selected three different alternatives of plastering usually adopted for external plastering of the houses. They are the following:

1) 12 mm thick plastering in 1:6 cement mortar :16CPLE or X_{84}
2) 12 mm thick plastering in 1:1:7 cement lime mortar: 117PLE or X_{85}
3) 12 mm thick plastering in 1:2:9 cement lime mortar : 129PLE or X_{86}

Total area of the plastering required externally is 13'x2(15+30)' = 1170 sq.ft.

7 windows and 1 door occupy 70 and 21 sq.ft. respectively.

Net area = 1170-91 = 1079 sq.ft. = 100.27 sq.mt.

Output constraint: can be written as follows:

$$X_{84} + X_{85} + X_{86} = 10.027 \qquad (7)$$

where X_j, $j = 84$ to 86 are specified in the units of 10 square metres each.

A.1.5.(b) Internal plastering: In addition to cement and cement-lime mortars, lime-surkhi mortars are also used for internal plastering of the buildings. In all, we have selected five different alternatives of plastering internally the house. They are:

(1) 12 mm thick plastering in 1:6 cement mortar : 16 CPLI or X_{79}
(2) 12 mm thick plastering in 1:1:7 cementlime motar:117PLIor X_{80}
(3) 12 mm thick plastering in 1:2:9 cementlime mortar: 129PLI. or X_{81}
(4) 12 mm thick plastering in 1:2 lime surkhi mortar:12LPLIor X_{82}
(5) 12 mm thick plastering in 1:1:1lime-surkhi-sand mortar : 111 PLI or X_{83}

Total area of the plastering required internally is to be calculated.

Length through which internal plastering is required is measured to be 174'.0. Required height = 12'.0.

Total area = 174'.0 x 12' = 2088 sq.ft.

Area occupied by the doors and windows is as follows:

5 doors (both sides) : 21 x 5x2 = 210 sq.ft.
1 door (one side) : 21 x1 x 1 = 21 sq.ft.
231 sq.ft.
7 windows (one side): 10x7 x 1 = 70 sq.ft.
301 sq.ft.

Net area = 2088 - 301 = 1787 sq.ft.
= 166.078 sq.mt.
= 16.61 units of 10 sq.mt. each.

Then the output constraint can be written as follows:

$$X_{79}+X_{80}+X_{81}+X_{82}+X_{83} = 16.61 \text{ units} \qquad (8)$$

where X_j, j = 79 to 83 are specified in the units of 10 sq.metres. Note that plastering the roof (internally) is avoided.

A4.6 Bed below flooring:

In order to keep out damp and white ants it is necessary to have a base of concrete below the flooring. The base separates the flooring and the earth. This concrete base is laid parallel to what is required on the finished surface. In general, this is of 4" thick. The total flooring area is 41.82 square metres. That implies, the total output of this concrete work is 41.82 sq.m. x 0.102 m = 4.78 cu.metres Usually this bed is of plain concrete. The following alternative concrete mixes are selected for this work:

1: 4 : 8 plain concrete work,

1: 3 : 6 plain concrete work,

1:2 : 4 plain concrete work.

Consider (T1) and (T2') constraints; X_j, j = 1 to 3 and 4 to 6 are precisely the same alternatives of concrete work. The output corresponding to the bed below the flooring also, can be accounted for by suitably modifying one of these two constraints. We modified (T2') as follows:

$$X_4+X_5+X_6-0.73205(X_{26}+....+X_{35})-1.000\ X_{36} = 4.778 \text{ cu.m.} \quad (T2)*$$

A.1.7 Technical constraints: While constructing the building the following points are to be noted:

(1) Brick foundation should not be provided below the superstructure of stone masonry. Only stone masonry foundation should be provided.

---

* See page 262.

(2) Generally, precast block superstructure is provided a foundation of precast block masonry only and also precast block foundation is not provided for any other type of superstructure.

(1) and (2) must be translated into constraints of mathematical form and introduced into our model. Let us take up one by one and derive these constraints:

<u>Stone masonry:</u> We know that

$$X_{47} + X_{48} + \dots + X_{54}$$

is the total amount (in cubic metres) of stone masonry in superstructure. Volume of this masonry in the superstructure per foot length of it is equal to

$$12' \times 1' \times 1' \qquad = 12 \text{ cft},$$

Then $\frac{1}{12} \quad (X_{47}+\dots+X_{54})$ (i)

is the length for which the superstructure is built in stone masonry.

We know that

$$X_{17} + X_{18}+\dots+ X_{24}$$

is the total amount (in cubic metres) of the stone masonry in foundation. Volume of this work in the foundation per foot length of it is equal to (as we calculated previously) 2.167 cft.

Then $\frac{1}{2.167} \quad (X_{17}+X_{18}+\dots+ X_{24})$ (ii)

is the length for which this type of foundation is built.

Now, point (1) implies that (ii) should at least be as much as (i). Hence the following technical constraint results:

$$(X_{17}+X_{18}+\ldots+X_{24})-\frac{2.167}{12}(X_{47}+X_{48}+\ldots+X_{54}) \geqq 0.$$

where

$$\frac{2.167}{12} = 0.1806.$$

However, ΣX_j, $j = 47$ to 54 is the net amount of stone masonry in the superstructure after deducting the portion corresponding to doors and windows. But the foundation has to be provided below the doors also. To take care of this extra amount required in $\sum_{j=17}^{24} X_j$, let us multiply 0.1806 by an arbitrary constant, 1.1.

$$0.1806 \times 1.1 = 0.1987$$

So the required technical constraint becomes

$$(X_{17}+X_{18}+\ldots+X_{24})-0.1987(X_{47}+\ldots+X_{54}) \geqq 0 \qquad (T3)$$

<u>Precast block masonry</u>

(i) <u>Load bearing walls:</u> We know that X_{55} is the amount (in cubic metres) of this type of work in the superstructure. Volume of this masonry in the superstructure per foot length of it is equal to

$$12' \times 1' \times 2/3 = 8 \text{ cft.}$$

Then $1/8\ X_{55}$ is the length for which the superstructure is built. We know that X_{55} is the total amount (in cubic metres) of precast block work in the foundation. Volume of this work in the foundation per foot length of it is equal to (as calculated previously) 1.5611 cft. Then $\frac{X_{25}}{1.5611}$ is the length for which this foundation is built. Now, point (2) implies that

$$\frac{X_{25}}{1.5611} - \frac{X_{55}}{8} = 0$$

or $$X_{25} - \frac{1.5611}{8} X_{55} = 0.$$

where $\frac{1.5611}{8} = 0.1951.$

Again, multiplying 0.1951 by 1.1 to take account of the length occupied by doors, the technical constraint becomes

$$X_{25} - 0.2146\ X_{55} = 0 \qquad (T4)$$

(ii) <u>Partition walls:</u> We know that X_{66} is the amount (in cubic metres) of this type of work in the superstructure. Volume of this masonry in the superstructure per foot length of it is equal to

$$12' \times 1' \times 1/3' = 4 \text{ cft.}$$

Then $\frac{X_{66}}{4}$ is the length for which the superstructure is built. We know that X_{36} is the total amount (in cubic metres) of precast block work in the foundation. Volume of this work in the foundation per foot length of it is equal to (as we calculated previously) 0.8911 cft. Then $\frac{X_{36}}{0.8911}$ is the length for which this type of foundation is built.

Now point (2) implies that

$$\frac{X_{36}}{0.8911} - \frac{X_{66}}{4} = 0$$

Again, multiplying by 1.1, to take account of the length occupied by doors, the technical constraint becomes

$$X_{36} - \frac{0.8911}{4} \times 1.1\ X_{66} = 0$$

or

$$X_{36} - 0.28736\ X_{66} = 0 \qquad (T5)$$

Consider the constraints T1 and T2. They were described as the output constraints for the foundation bed below the load bearing and partition walls. However, it is to be noted that X_j, j =1 to 3 and 4 to 6 are technically related to X_j, j = 7 to 25 and 26 to 36 respectively in these two constraints. Hence, these two constraints are of technical nature basically. So, these two constraints, along with T3 , T4 and T5, are accounted in the set of technical constraints.

A.1.8 Summary of the output and technical constraints for building-construction:

In summary, all the output and technical constraints to be satisfied in building the house are written below:

1. $$\sum_{j=1}^{3} X_j - 0.9260 \sum_{j=7}^{16} X_j - 1.15370 \sum_{j=17}^{24} X_j - 0.5708 X_{25} = 0$$

2. $$\sum_{j=4}^{6} X_j - 0.73205 \sum_{j=26}^{35} X_j - 1.0\ X_{36} = 4.778$$

3. $$\sum_{j=7}^{16} X_j + 0.7758 \sum_{j=17}^{24} X_j + 1.0809 X_{25} = 2.8671$$

4. $$\sum_{j=26}^{35} X_j + 0.8942 X_{36} = 1.5484$$

5. $$\sum_{j=37}^{46} X_j + 0.75 \sum_{j=47}^{54} X_j + 1.125 X_{55} = 14.02$$

6. $$\sum_{j=56}^{65} X_j + 1.125 X_{66} = 7.30$$

7. $$\sum_{j=17}^{24} X_j - 0.1987 \sum_{j=47}^{54} X_j \geq 0$$

8. $X_{25} - 0.2146\, X_{55} = 0$

9. $X_{36} - 0.26736\, X_{66} = 0$

10. $\sum_{j=67}^{73} X_j = 41.82$

11. $\sum_{j=74}^{78} X_j = 4.182$

12. $\sum_{j=79}^{83} X_j = 16.61$

13. $\sum_{j=84}^{86} X_j = 10.027$

A.2 Road Construction

In this section we present the engineering calculations involved behind the study on appropriate technology for road-construction. The proposed national high way has the following characteristics:

formation width = 12 metres

carriage way width = 7 metres

wheel load = 12000 lb.

The analysis is carried out for one kilometre length of the road taking different natures of the soil into account. The different natures of the soil considered correspond to c.b.r. values of 7, 10, 15 and 20. Alternative techniques corresponding to the following roads are considered in this project:

(a) Asphalt road over water bound macadam work
(b) Cement concrete road with cement-concrete sub-base
(c) Cement concrete road with waterbound macadam subbase
(d) Cement concrete road with lime-concrete subbase
(e) Puzzolana concrete road with lime-concrete subbase.

The following stages are involved in the construction of the above roads:

Stage 1 : Earth excavation
Stage 2 : Preparation of subgrade
Stage 3 : Soling work
Stage 4 : Subbase work

Stage 5 : Wearing surface or waterbound macadam work for asphalt roads

Stage 6 : Premix carpet

Stage 7 : Sealing coat

Stage 8 : Wearing coat

In the following sub sections details regarding the engineering considerations specification of output levels and derivation of output and technical constraints for different stages of the road construction are described. The description corresponds to the c.b.r. value of 15 per cent. Different output levels corresponding to different c.b.r. values can be noted from the Table A.2.1. on pages 272 and 273.

A.2.1 <u>Excavation or Earth Work:</u> We have to estimate the quantity of earthwork to be done in making the preliminaries of sectioning for bringing the formation width of the road to 12 metres. This quantity normally varies from place to place where the road is built. Hence, we decided to account for the quantity of earthwork per kilometre of the roadway as an average of such work observed from different national highways in India. Table A.2.2. provides the details of these observations:

Table A.2.2

National Highway	Earthwork per kilometre (in m^3)
1) Anantapur bye-pass road of Kurnool-Bangalore Highway (National Highway 7)	10277.555
2) Nelamangala bye-pass road of Banaghlore-Poona Highway (National Highway 4)	16745.222

3) Etawah bye-pass road on Agra-Bhoginpur Highway (National Highway 2)	32527.38
4) Nipani bye-pass road on Bangalore-Poona Highway (National Highway 4)	8985.1282
5) Dharmavaram bye-pass road on Vijayawada-Visakhapatnam Highway (National Highway 5)	19168.096
	87703.3812

Average earthwork per kilometre long road = 87703.3812/5

= 17540.676 (m^3)

per kilometre

X_1 (capital-intensive technique) and X_2 (labour-intensive technique) are the two alternatives available for earthwork and excavation. So the output constraint becomes

$$X_1 + X_2 = 17540.676 \qquad (1)$$

where X_j $j = 1,2,$ are specified in the units of m^3.

A.2.2. Preparation of Subgrade: Total area of the preparation of subgrade is equal to the product of the formation width and length of the road-way (i.e.) 12 mx1000m = 12000 m^2. We have only one technique (X_3) available for doing this work. Hence the output constraint becomes

$$X_3 = 120 \qquad (2)$$

where X_3 is specified in the units of 100 Sq. m.

A.2.3. Soling and Subbase Works Stage: After the preparation of subgrade either soling work or subbase work is carried out. Soling work is required if the final form of the road is a bituminous (asphalt) road. Subbase work is required if the final form of the road is a concrete road. The output required of the soling work is 1066.8 m^3, and of the subbase work is 533.4 m^3 (see table A.2.1). The following are the different alternatives for these works:

X_4 = Soling activity (m^3)

X_5 = 1:4:8 cement concrete subbase (m^3)

X_6 = W.B.M. subbase (m^3)

X_7 = Lime concrete subbase for cement concrete wearing coat (m^3)

X_8 = Lime concrete subbase for puzzolana concrete wearing coat (m^3)

Then the output constraint becomes

$$0.5X_4+X_5+X_6+X_7+X_8 = 533.4 \qquad (3)$$

where $\frac{533.4}{1066.8} = 0.5$.

A.2.4 W.B., premix carpet and sealing coat works for asphalt road: Soling is 6" (15.24 cm) thick and WBM is 3" (7.62 cm) thick. X_5 and X_9 are the techniques for soling and WBM work, specified in m^3. Then

$$\text{Area of the soling work} = \frac{X_4}{0.1524} \text{ sq.m, and}$$

$$\text{Area of the WBM work} = \frac{X_9}{0.0762} \text{ sq. m.}$$

Total area of the WBM work required is equal to the area of soling work i.e.

$$\frac{X_9}{0.0762} = \frac{X_4}{0.1524}$$

or

$$X_9 - 0.5\,X_4 = 0 \qquad (4)$$

where $\frac{0.0762}{0.1524} = 0.5$.

Let X_{10} be the technique for the work of premix carpet specified in the units of sq.metres. Total area of the premix carpet required is equal to the area of WBM work. Then

$$X_{10} = \frac{X_9}{0.0762}$$

or

$$X_{10} - 13.12336\ X_9 = 0 \qquad (5)$$

where $\frac{1}{0.0762} = 13.12336$.

Let X_{11} be the technique for the work of sealing coat specified in the units of sq.metres. Total area of the sealing coat required is equal to the area of premix carpet. i.e.

$$X_{11} = X_{10}$$

or

$$X_{11} - X_{10} = 0 \qquad (6)$$

A.2.5 Wearing coat for concrete roads: Two types of wearing coat are available: cement concrete wearing coat (X_{12}) and puzzolana concrete wearing coat (X_{13}). The former (X_{12}) is laid over any of the subbase X_5, X_6 and X_7 whereas the latter (X_{13}) is laid over the subbase X_8 only, which are mentioned in section A.2.3. Note also that the area of the wearing coat is equal to the area of the subbase work in total.

Thickness of the subbases (X_5, X_6, X_7 and X_8) = 3" = 7.62 cm.

Thickness of the wearing coats (X_{12} and X_{13}) = 9.5" = 24.13 cm.

Total area of the subbases (X_5, X_6 and X_7) = $\frac{X_5+X_6+X_7}{0.0762}$ sq.m.

Total area of the subbase (X_8) = $\frac{X_8}{0.0762}$ sq.m.

Total area of the wearing coat (X_{12}) = $\frac{X_{12}}{0.2413}$ sq.m.,

Total area of the wearing coat (X_{13}) = $\frac{X_{13}}{0.2413}$ sq.m.

where X_{12} and X_{13} are specified in the units of cu.m. Then (a) for cement concrete wearing coat (X_{13})

$$\frac{X_{12}}{0.2413} - \frac{X_5+X_6+X_7}{0.0762} = 0$$

or

$$0.3157891\ X_{12} - X_5 - X_6 - X_7 = 0 \qquad (7)$$

and

(b) for puzzolana concrete wearing coat (X_{13})

$$\frac{X_{13}}{0.2413} - \frac{X_8}{0.0762} = 0$$

or

$$X_{13} - 3.1667\ X_8 = 0 \qquad (8)$$

become the technical-cum-output constraints.

Note $\frac{0.0762}{0.2413} = 0.3157891$ and $\frac{0.2413}{0.0762} = 3.1667$.

4.2.6 Life-times of different roads: In the end, we have to account for the difference in life times of different roads. We have the following information available on their life times:

Premix bituminous carpet = 8 to 15 years.

All concrete roads = 24 to 40 years.

We will take the lower bounds of the above figures as the life times of the respective types of roads. To compare them, we will compare the expenditure streams over a period of 24 years. Since the life of the premix carpet and sealing coat works of an asphalt road is 8 years, these activities have to be repeated after every 8 years. Subgrade preparation, soling and waterbound macadam activities of the asphalt road need not be repeated.

It is also to be noted that concrete roads require no maintenance expenditure, However, in the case of asphalt roads the premix carpet and sealing coat activities not only require to be relaid once in every 8 years but also involve some maintenance expenditure annually. We assume that 5 percent of the total cost of these activities is incurred as maintenance expenditure every year on asphalt roads. This is a high estimate and should make asphalt roads less attractive than they in fact are. These future costs involved in re-laying and maintaining the premix carpet and sealing coat activities are discounted as follows:

Let the discount rate be r percent, and the total cost of premix carpet and sealing coat be Rs.X/-. Then the discounted stream of the above mentioned future expenditures is as follows:

$$X\left[\frac{1}{(1+r)^8}+\frac{1}{(1+r)^{16}}\right]+0.05X\left[\sum_{n=1}^{7}\left(\frac{1}{(1+r)^n}\right)+\sum_{n=9}^{15}\left(\frac{1}{(1+r)^n}\right)+\sum_{n=17}^{23}\left(\frac{1}{(1+r)^n}\right)\right]$$

$= 0.51855\ X$ at $r = 20$ percent.

Adding the cost of present construction Rs.X/- to it, the total comes to Rs. 1.51855X/-. This can be treated as either 1.51855 times the present cost of construction or the present output level required. This means that all the future costs involved are equivalent to the cost of an additional 0.51855 times the present output of these two activities. Hence the output coefficient of the premix carpet activity is deflated by

$\frac{1}{1.51855}$ (=0.658523). Thus the output coefficient of X_{11} in equation (5') is modified to 0.658523 from 1.0, and equation (5') becomes

$$0.658523 X_{10} - 13.12336 X_9 = 0 \qquad (5)$$

The output coefficient of the sealing coat activity need not be changed because it is technically related to the premix carpet activity by equation (6), and gets automatically adjusted to that level.

However, a separate exercise is carried out assuming that the life of concrete road is 40 years instead of 24 years*. Same discounting procedure as described above is adopted and the output coefficient of the premix carpet activity in equation (5) is determined accordingly.

A.2.7 <u>Summary of the technical and output constraints:</u> In summary, we write all the technical and output constraints to be satisfied in constructing the specified road below:

(1) $X_1 + X_2 = 17540.076$

(2) $X_3 = 120.0$

(3) $0.5X_4+X_5+X_6+X_7+X_8 = 533.4$

(4) $X_9 - 0.5 X_4 = 0$

(5) $0.658523 X_{10} - 13.12336 X_9 = 0$

(6) $X_{11}-X_{10} = 0$

(7) $0.3157891 X_{12}- X_5-X_6-X_7 = 0$

(8) $X_{13} - \text{[illegible]}.1667 X_8 = 0$

---

* See Section 6.8.7.

Table A.8.1: Output levels per one km. length of different roads corresponding to different c.b.r. values*

Formation width = 12 m. Carriage way width = 7 m Wheel load = 12000 lb.

For all types of roads: Total earthwork/excavation = 17540.676** m^3/km; Total area for preparation of subgrade = 12 x 1000 = 12000 sq. m.

Type of Road	Stages of construction	Output required for various c.b.r. values			
		c.b.r = 15	c.b.r = 7	c.b.r = 10	c.b.r. = 20
1. Asphalt (or Bituminous Road	i) Soling	soling is 6" =15.24 cm thick Qnty.of work =1000x7.00x.1524=1066.8m^3	soling is 11" =27.94 cm thick qnty.of work =1000x7x.2794 =1955.8m^3	soling is 9" =22.86 cm thick qnty.of work =1000x7x.2286 = 1600.2m^3	soling is 5" =12.7 cm thick. Qnty.of work =1000x7x.127 = 889.0m^3
	ii) Waterbound Macadam	WBM is 3" =7.62 cm thick qnty.of work =1000x7x.0762 =533.4 m^3	WBM is 3" =7.62 cm thick. Qnty.of work =1000x7x.0762 =533.4 m^3	WBM is 3" =7.62 cm thick qnty.of work =1000x7x.0762 =533.4 m^3	WBM is 3" =7.62 cm thick. Qnty.of work =1000x7x.0762 =533.4 m^3
	iii) Premix carpet (2.5 cm thick)	Area of work =1000x7 =7000 m^2	Area of work =1000x7 =7000 m^2	Area of work =1000x7 =7000 m^2	Area of work =1000x7 =7000 m^2
	iv) Sealingcoat (1.5 cm thick)	Area of work =1000x7 =7000 m^2	Area of work =1000x7 =7000 m^2	Area of work =1000x7 =7000 m^2	Area of work =1000x7 =7000 m^2
2. Cement concrete Road (with concrete subbase)	i) Subbase (1:4:8 concrete)	Thickness of subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	Thickness of subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	Thickness of subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	Thickness of subbase is 3" Qnty.of work =1000x7x.0762 =533.4 m^3
	ii) Wearing coat (1:2:4 concrete)	w.coat is 9.5" =24.13 cm thick Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" =24.13 cm thick. Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" =24.13 cm thick Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" =24.13 cm thick. Total qnty. of work =1000x7x.2413 =1689.1 m^3

Table A.2.1 (cont.)

3. Cement concrete Road(with WBM subbase)	i) Subbase (WBM)	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work 1000x7x.0762 = 533.4 m^3
	ii) Wearing coat(1:2:4 concrete)	w.coat is 9.5" Total qnty. of work = 1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3
4. Cement concrete Road(with lime concrete subbase)	i) Subbase (1:1:1Lime concrete)	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3
	ii) Wearing coat(1:2:4 concrete)	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3
5. Puzzolana Concrete Road(with puzzolana subbase)	i) Subbase (puzzolana)	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3	subbase is 3" Qnty.of work =1000x7x.0762 = 533.4 m^3
	ii) Wearing coat (puzzolana)	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3	w.coat is 9.5" Total qnty. of work =1000x7x.2413 = 1689.1 m^3

* Values of thicknesses corresponding to soling, WBM, subbases etc. used in this table are deduced from table 6.8.4.2. Measurementsof subbases and wearing coats correspond to their thickness.

** See section A.2.1 in appendix A.

Note: Costs involved on dummy joints and expansions joints of the concrete roads are taken to be miscellaneous and added to the objective function coefficients of the wearing coat activities of the concrete roads. See 2.2.2.

DATA

D.1 : Data for the matrices 'B' and 'S' and indirect capital for building and road construction

The following data correspond to the matrices 'B' and 'S' described in the analytical programming model of Chapter IV. The elements 'b_{ij}'s of the 'B' matrix denote the following:

b_{ij} = amount of ith primary resource required in producing a unit amount of jth intermediate input.

The elements 's_{ij}'s of the 'S' matrix denote the following:

s_{ij} = mandays required of ith wage-group labour in producing a unit amount of jth intermediate input.

The data includes also the information on the rental value of capital equipment needed in producing the intermediate inputs required in building and road construction. These values are given for different interest-rates, and referred in the text as 'indirect capital'.

Note: 1. Capital rentals are in the units of Rs.

2. S and B matrices for the building and road construction contain the columns of the following matrix (see next page) corresponding to only those intermediate inputs required in the respective constructions.

3. Last six rows of thematrix correspond to the rows of 'S' matrix described in Chapter IV. Rest of the rows correspond to the B matrix described there.

Intermediate input Primary Resources	Cement (tonnes)	Bricks (000)	Coarse sand (m^3)	Fine sand (m^3)	Stone aggrt.& ballast (m^3)	Lime (qntl.)
Elect.(Kwh)	80.0	-	-	-	-	-
Coal (tonnes)	0.33	0.2	-	-	-	0.03
Limestone(")	1.15	-	-	-	-	0.187
Gypsum(tonnes)	0.04	-	-	-	-	-
Clay (tonnes)	0.2	4.91	-	-	-	-
Water (tonnes)	3.0	-	-	-	-	-
Ironore(")	-	-	-	-	-	-
Manganeseore(")	-	-	-	-	-	-
Dolomite(")	-	-	-	-	-	-
Coarsesand(m^3)	-	.1132	1.0	-	-	-
Finesand(m^3)	-	-	-	1.0	-	-
Qry.stone(m^3)	-	-	-	-	1.1	-
Sandstone(sq.m)	-	-	-	-	-	-
Bitumen(tonne)	-	-	-	-	-	-
Diesel(litre)	-	-	-	-	-	-
Moorum (m^3)	-	-	-	-	-	-
Capital rental						
i=5 p.c.	32.87	4.93	-	-	1.42	0.80
i=10 p.c.	48.10	5.74	-	-	1.79	1.09
i=15 p.c.	65.42	6.61	-	-	2.19	1.41
i=20 p.c.	84.10	7.52	-	-	2.62	1.77
i=25 p.c.	103.58	8.47	-	-	3.08	2.14
Misc. (Rs.)	130.90	10.03	-	-	-	4.41
Labour of wage group(Rs./day)						
0 - 4	-	3.1703	0.230	0.230	2.3974	1.3094
4 - 5	-	0.9333	-	-	-	-
5 - 6	-	-	-	-	-	0.1738
6 - 8	0.5025	0.30	-	-	0.0333	-
8 - 10	0.3196	0.0666	-	-	0.0111	-
≥ 10	0.2710	-	-	-	-	-

	Surkhi (m^3)	Stone at Quarry (m^3)	Th.bond stone (nos.)	Steel (Kg.)	Sand stone (sq.m.)	Bitumen (tonne)
El.	-	-	-	-	-	-
Co.	0.131	-	-	.002	-	-
Li.	-	-	-	.0006	-	-
Gy.	-	-	-	-	-	-
Cl.	2.312	-	-	-	-	-
Wa.	-	-	-	-	-	-
I.o.	-	-	-	.0019	-	-
M.o.	-	-	-	.00013	-	-
Po.	-	-	-	.00009	-	-
C.s.	0.0533	-	-	-	-	-
F.s.	-	-	-	-	-	-
Q.s.	-	1.05	.2519	-	-	-
Snd.s.	-	-	-	-	1.10	-
Bit.	-	-	-	-	-	1.0
Di.	-	-	-	-	-	-
Moor.	-	-	-	-	-	-
<u>Capital rental</u>						
i=5 p.c.	1.16	0.64	0.04	0.30	0.93	-
i=10 p.c.	1.35	0.80	0.05	0.43	1.17	-
i=15 p.c.	1.55	0.98	0.06	0.58	1.43	-
i=20 p.c.	1.77	1.17	0.07	0.75	1.72	-
i=25 p.c.	1.99	1.37	0.08	0.93	2.02	-
Misc. (Rs)	13.41	-	0.02	0.55	-	-
<u>Labour of wage group(Rs./day)</u>						
0 - 4	0.745	0.0444	0.0549	-	.001776	-
4 - 5	0.21935	-	-	0.0011	-	-
5 - 6	-	-	-	-	-	-
6 - 8	0.0705	0.0333	.000763	-	.001332	-
8 -10	0.01565	0.0111	.000254	0.00095	.000444	-
$\geq$ 10	-	-	-	-	-	-

	Diesel (litre)	Moorum (m^3)	Soling stone (m^3)	Stone metal(WBM) (m^3)	Coal (qntl.)
El.	-	-	-	-	-
Co.	-	-	-	-	0.1
Li.	-	-	-	-	-
Gy.	-	-	-	-	-
Cl.	-	-	-	-	-
Wa.	-	-	-	-	-
I.o.	-	-	-	-	-
M.o.	-	-	-	-	-
Dc..	-	-	-	-	-
C.s.	-	-	-	-	-
F.s.	-	-	-	-	-
Q.s.	-	-	1.1	1.1	-
Sand.s.	-	-	-	-	-
Bit.	-	-	-	-	-
Di.	1.0	-	-	-	-
Moor.	-	1.0	-	-	-
<u>Capital rental</u>					
i=5 p.c.	-	-	0.84	0.85	-
i=10 p.c.	-	-	1.05	1.07	-
i=15 p.c.	-	-	1.29	1.31	-
i=20 p.c.	-	-	1.54	1.57	-
i=25 p.c.	-	-	1.81	1.84	-
Misc.(Rs.)	-	-	0.04	0.17	-
<u>Labour of wage group(Rs./day)</u>					
0 - 4	-	-	0.5	0.5	-
4 - 5	-	-	-	-	-
5 - 6	-	-	-	-	-
6 - 8	-	-	.01665	.01665	-
8 -10	-	-	.00555	.00555	-
$\geq$ 10	-	-	-	-	-

D.2: Data for the matrices 'A' and 'D' and direct capital for building and road construction:

The following data correspond to the matrices 'A' and 'D' described in the analytical programming model of Chapter IV. The elements 'a_{ij}'s of the 'A' matrix denote the following:

a_{ij} = amount of ith intermediate input required for unit operation of jth activity.

The elements 'd_{ij}'s of the D matrix denote the following:

d_{ij} = man-days required of ith wage-group labour for unit operation of jth activity.

The data include also the information on the objective coefficients of the activities in building and road construction. In the case of road-construction information on machine-days of the capital-equipment required in the unit operation of the activities, also is given. The rental values calculated from this information are referred in the text as 'direct capital'. Direct capital is nil for building construction.

D.2.1: BUILDING CONSTRUCTION

Technique X_j Intermediate Inputs (A-matrix)	148FBL X_1	136FBL X_2	124FBL X_3	148FBP X_4	136FBP X_5	124FBP X_6	130BFL X_7	120BFL X_8
Cement (tonnes)	0.17	0.22	0.32	0.17	0.22	0.32	0.13	0.17
Bricks (thousand)	-	-	-	-	-	-	0.494	0.494
Coarsesand (m^3)	0.47	0.46	0.445	0.47	0.46	0.445	0.27	0.19
Finesand (m^3)	-	-	-	-	-	-	-	-
St.Aggregate (m^3)	0.89	0.89	0.85	0.89	0.89	0.85	-	-
Unslaked lime(qntl.)	-	-	-	-	-	-	-	-
Surkhi (m^3)	-	-	-	-	-	-	-	-
Stone at quarry(m^3)	-	-	-	-	-	-	-	-
Through & bondstones (nos.)	-	-	-	-	-	-	-	-
Steel (Kg.)	-	-	-	-	-	-	-	-
Sandstone (sq.m.)	-	-	-	-	-	-	-	-
Direct Labour(M.d)* (D.matrix)Rs./day								
DL1 0-4	1.5	1.5	1.5	1.5	1.5	1.5	1.22	1.22
DL2 4-5	0.31	0.31	0.31	0.31	0.31	0.31	0.28	0.28
DL3 5-6	-	-	-	-	-	-	-	-
DL4 6-8	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.35
DL5 8-10	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.35
DL6 > 10	-	-	-	-	-	-	-	-
Objective function Coefficients								
Total Costs(C_j in Rs)	32.37	33.02	33.50	32.37	33.02	33.50	31.30	31.06
Direct labour costs	7.50	7.50	7.50	7.50	7.50	7.50	11.12	11.12
Indirect labour costs	9.66	10.11	10.64	9.66	10.11	10.64	10.36	10.65
Transport costs	10.06	10.26	10.21	10.06	10.26	10.21	9.82	9.29
Miscellaneous costs	5.15	5.15	5.15	5.15	5.15	5.15	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

* mandays.

(D.2.1: cont.)

Technique X_j	14CBFL	16CBFL	116BFL	129BFL	118BFL	113BFL	111BFL	12LBFL
Intermediate Inputs (A-matrix)	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
Cement (tonnes)	0.095	0.0625	0.0625	0.0425	0.0475	0.105	-	-
Bricks (thousand)	0.494	0.494	0.494	0.494	0.494	0.494	0.494	0.494
Coarse sand (m^3)	0.27	0.27	0.27	-	-	0.2145	0.119	-
Fine sand (m^3)	-	-	-	0.27	0.27	-	-	-
St.Aggregate (m^3)	-	-	-	-	-	-	-	-
Unslaked lime (qntl.)	-	-	0.28	0.38	0.21	0.455	0.75	0.75
Surkhi (m^3)	-	-	-	-	-	-	0.119	0.24
Stone at quarry (m^3)	-	-	-	-	-	-	-	-
Through'bond stones	-	-	-	-	-	-	-	-
Steel (Kg.)	-	-	-	-	-	-	-	-
Sandstone (Sq.m.)	-	-	-	-	-	-	-	-
Direct labour (m.d.) D-matrix(Rs./day)								
DL1 0-4	1.22	1.22	1.295	1.295	1.295	1.295	1.295	1.295
DL2 4-5	0.28	0.28	0.313	0.313	0.313	0.313	0.313	0.313
DL3 5-6	-	-	-	-	-	-	-	-
DL4 6-8	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
DL5 8-10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
DL6 $\geq$ 10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs (C_j in Rs)	30.84	30.42	32.44	32.77	31.96	33,48	33.71	34.14
Direct labour costs	11.12	11.12	11.53	11.53	11.53	11.53	11.53	11.53
Indirectlabour costs	10.04	9.75	11.19	11.53	10.70	12.43	13.44	13.86
Transport costs	9.68	9.55	9.72	9.71	9.73	9.52	8.74	8.75
Miscellaneous costs	-	-	-	-	-	-	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

(D.2.1: cont.)

Technique X_j / Intermediate inputs (A-Matrix)	14CCFL X_{17}	16CCFL X_{18}	111CFL X_{19}	118CFL X_{20}	14CRFL X_{21}	16CRFL X_{22}	111RFL X_{23}	118RFL X_{24}
Cement (tonnes)	0.114	0.075	-	0.057	0.13	0.0833	-	0.0627
Bricks (thousand)	-	-	-	-	-	-	-	-
Coarse sand (m^3)	0.321	0.321	-	-	0.36	0.35	-	-
Fine sand (m^3)	-	-	0.1425	0.321	-	-	0.158	0.35
St.Aggregate (m^3)	-	-	-	-	-	-	-	-
Unslaked lime (qntl.)	-	-	0.903	0.252	-	-	1.00	0.28
Surkhi (m^3)	-	-	0.1425	-	-	-	0.158	-
Stone at quarry(m^3)	1.10	1.10	1.21	1.21	1.00	1.00	1.00	1.00
Through&bond Stones	7	7	7	7	7	7	7	7
Steel (Kg.)	-	-	-	-	-	-	-	-
Sandstone (sq.m.)	-	-	-	-	-	-	-	-
Direct labour (m.d) D-matrix(Rs./day)								
DL 1 0-4	2.13	2.13	2.22	2.22	1.98	1.98	2.08	2.08
DL 2 4-5	0.18	0.18	0.225	0.225	0.19	0.19	0.24	0.24
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	2.12	2.12	2.12	2.12	1.07	1.07	1.07	1.07
DL 5 8-10	-	-	-	-	-	-	-	-
DL 6 ≥ 10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs(C_j in Rs)	37.93	37.42	42.22	38.95	29.97	29.27	33.78	30.12
Direct labour costs	23.14	23.14	23.67	23.67	15.31	15.31	15.90	15.90
Indirect labour cost	3.21	2.86	7.35	4.05	3.34	2.91	7.83	4.17
Transport costs	11.58	11.42	11.20	11.23	11.32	11.05	10.05	10.05
Miscellaneous costs	-	-	-	-	-	-	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

(D.2.1: cont.)

Technique X_j	PCHBFL	13CBFP	12CBFP	14CBFP	16CBFP	116BFP	129BFP	118BFP
Intermediate Inputs (A-matrix)	X_{25}	X_{26}	X_{27}	X_{28}	X_{29}	X_{30}	X_{31}	X_{32}
Cement (tonnes)	0.16325	0.13	0.17	0.095	0.0625	0.0625	0.0425	0.0475
Bricks (thousand)	-	0.494	0.494	0.494	0.494	0.494	0.494	0.494
Coarsesand (m^3)	0.92	0.27	0.19	0.27	0.27	0.27	-	-
Finesand (m^3)	-	-	-	-	-	-	0.27	0.27
St.Aggregate (m^3)	-	-	-	-	-	-	-	-
Unslaked lime (qntl.)	0.0823	-	-	-	-	0.28	0.38	0.21
Surkhi (m^3)	-	-	-	-	-	-	-	-
Stone at quarry (m^3)	-	-	-	-	-	-	-	-
Through&bond stones	-	-	-	-	-	-	-	-
Steel (Kg.)	-	-	-	-	-	-	-	-
Sandstone (sq.m.)	-	-	-	-	-	-	-	-
Direct labour (m.d) D-matrix(Rs./day)								
DL 1 0-4	4.52	1.22	1.22	1.22	1.22	1.295	1.295	1.295
DL 2 4-5	-	0.28	0.28	0.28	0.28	0.313	0.313	0.313
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	[illegible]	0.35	0.35	0.35	0.35	0.35	0.35	0.35
DL 5 8-10	1.325	0.35	0.35	0.35	0.35	0.35	0.35	0.35
DL 6 ≥ 10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs (C_j in Rs)	38.85	31.30	31.06	30.84	30.42	32.44	32.77	31.96
Direct labour costs	27.48	11.12	11.12	11.12	11.12	11.53	11.53	11.53
Indirect labourcosts	2.63	10.36	10.65	10.04	9.75	11.19	11.53	10.70
Transport costs	8.74	9.82	9.29	9.68	9.55	9.72	9.71	9.73
Miscellaneous costs	-	-	-	-	-	-	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

(D.21.: cont.)

Technique X_j Intermediate Inputs (A-matrix)	113DFP X_{33}	111BFP X_{34}	12LBFP X_{35}	PCHBFP X_{36}	13CBLW X_{37}	12CBLW X_{38}	14CBLW X_{39}	16CBLW X_{40}
Cement (tonnes)	0.105	-	-	0.16325	0.13	0.17	0.095	0.0625
Bricks (thousand)	0.494	0.494	0.494	-	0.494	0.494	0.494	0.494
Coarsesand (m^3)	0.2145	0.119	-	0.92	0.27	0.19	0.27	0.27
Finesand (m^3)	-	-	-	-	-	-	-	-
St.Aggregate (m^3)	-	-	-	-	-	-	-	-
Unslaked (qntl.)	0.455	0.75	0.75	0.0028	-	-	-	-
Surkhi (m^3)	-	0.119	0.24	-	-	-	-	-
Stone at quarry (m^3)	-	-	-	-	-	-	-	-
Through&bond stones	-	-	-	-	-	-	-	-
Steel (kg.)	-	-	-	-	-	-	-	-
Sandstone (Sq.m.)	-	-	-	-	-	-	-	-
Direct labour (m.d) (D-matrix) (Rs./day)								
DL 1 0-4	1.295	1.295	1.295	4.52	1.55	1.55	1.55	1.55
DL 2 4-5	0.313	0.313	0.313	-	0.28	0.28	0.28	0.28
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	0.35	0.35	0.35	-	0.43	0.43	0.43	0.43
DL 5 8-10	0.35	0.35	0.35	1.325	0.43	0.43	0.43	0.43
DL 6 $\geq$ 10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs (C_j in Rs)	33.48	33.71	34,14	38.85	33.72	33.48	33.26	32.84
Direct labour costs	11.53	11.53	11.53	27.48	13.54	13.54	13.54	13.54
Indirect labour cost	12.43	13.44	13.86	2.63	10.36	10.65	10.04	9.75
Transport costs	9.52	8.74	8.75	8.74	9.82	9.29	9.68	9.55
Miscellaneous costs	-	-	-	-	-	-	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

(D.2.1: cont.).

Technique X_j Intermediate Inputs (A-matrix)	116BLW X_{41}	129BLW X_{42}	118BLW X_{43}	113BLW X_{44}	111BLW X_{45}	12LBLW X_{46}	14CCLW X_{47}	16CCLW X_{48}
Cement (tonnes)	0.0625	0.0425	0.0475	0.105	-	-	0.114	0.075
Bricks (thousand)	0.494	0.494	0.494	0.494	0.494	0.494	-	-
Coarsesand (m^3)	0.27	0.27	0.27	0.2145	0.119	-	0.321	0.321
Finesand (m^3)	-	-	-	-	-	-	-	-
St.Aggregate(m^3)	-	-	-	-	-	-	-	-
Unslacked lime (qntl.)	0.28	0.38	0.21	0.455	0.75	0.75	-	-
Surkhi (m^3)	-	-	-	-	0.119	0.24	-	-
Stone at quarry(m^3)	-	-	-	-	-	-	1.1	1.1
Through&bond stones	-	-	-	-	-	-	7	7
Steel (Kg.)	-	-	-	-	-	-	-	-
Sandstone (sq.m.)	-	-	-	-	-	-	-	-
Direct labour (m.d) (D-matrix)(Rs/day)								
DL 1 0-4	1.625	1.625	1.625	1.625	1.625	1.625	2.48	2.48
DL 2 4-5	0.313	0.313	0.313	0.313	0.313	0.313	0.09	0.09
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	0.43	0.43	0.43	0.43	0.43	0.43	2.38	2.38
DL 5 8-10	0.43	0.43	0.43	0.43	0.43	0.43	-	-
DL 6 ≥10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs(C_j in Rs)	34.86	35.19	34.38	35.90	36.13	36.56	40.55	40.04
Direct labour costs	13.95	13.95	13.95	13.9	13.95	13.95	25.76	25.76
Indirect labourcosts	11.19	11.53	10.70	12.43	13.44	13.86	3.21	2.86
Transport costs	9.72	9.71	9.73	9.52	8.74	8.75	11.58	11.42
Miscellaneous costs	-	-	-	-	-	-	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

(D.2.1: cont.)

Technique X_j Intermediate inputs (A-matrix)	14CRLW X_{49}	16CRLW X_{50}	111CLW X_{51}	118CLW X_{52}	111RLW X_{53}	118RLW X_{54}	PCIBLW X_{55}	13CBLP X_{56}
Cement (tonnes)	0.13	0.0833	-	0.057	-	0.0627	0.16325	0.13
Bricks (thousand)	-	-	-	-	-	-	-	0.494
Coarsesand (m^3)	0.36	0.35	-	-	-	-	0.92	0.27
Finesand (m^3)	-	-	0.1425	0.321	0.158	0.35	-	-
St.Aggregate(m^3)	-	-	-	-	-	-	-	-
Unslaked lime (qntl.)	-	-	0.903	0.252	1.0	0.28	0.0828	-
Surkhi (m^3)	-	-	0.1425	-	0.15	-	-	-
Stone at quarry(m^3)	1.0	1.0	1.21	1.21	1.0	1	-	-
Through-bond stones	7	7	7	7	7	7	-	-
Steel (Kg.)	-	-	-	-	-	-	-	-
Sandstone (sq.m.)	-	-	-	-	-	-	-	-
Direct labour (m.d) (D-matrix) (Rs/day)								
DL 1 0-4	2.36	2.36	2.57	2.57	2.46	2.46	4.52	1.55
DL 2 4-5	0.165	0.165	0.225	0.225	0.24	0.24	-	0.28
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	1.34	1.34	2.38	2.38	1.34	1.34	-	0.43
DL 5 8-10	-	-	-	-	-	-	1.325	0.43
DL 6 ≥10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs (C_j in Rs)	33.08	32.38	45.26	41.99	37.00	33.34	38.85	33.72
Direct labour costs	18.42	18.42	26.71	26.71	19.12	19.12	27.48	13.54
Indirect labour cost	3.34	2.91	7.35	4.05	7.83	4.17	2.63	10.36
Transport costs	11.32	11.05	11.20	11.23	10.05	10.05	8.74	9.82
Miscellaneous costs	-	-	-	-	-	-	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

(D.2.1: contd.)

Technique X_j	12CBLP	14CBLP	16CBLP	116BLP	129BLP	118BLP	113BLP	111BLP
Intermediate Inputs (A-matrix)	X_{57}	X_{58}	X_{59}	X_{60}	X_{61}	X_{62}	X_{63}	X_{64}
Cement (tonnes)	0.17	0.095	0.0625	0.0625	0.0425	0.0475	0.105	-
Bricks (thousand)	0.494	0.494	0.494	0.494	0.494	0.494	0.494	0.494
Coarsesand (m^3)	0.19	0.27	0.27	0.27	0.27	0.27	0.2145	0.119
Finesand (m^3)	-	-	-	-	-	-	-	-
St.Aggregate (m^3)	-	-	-	-	-	-	-	-
Unslaked lime (qntl.)	-	-	-	0.28	0.38	0.21	0.455	0.75
Surkhi (m^3)	-	-	-	-	-	-	-	0.119
Stone at quarry(m^3)	-	-	-	-	-	-	-	-
Through&bond stones	-	-	-	-	-	-	-	-
Steel (Kg.)	-	-	-	-	-	-	-	-
Sandstone (sq.m)	-	-	-	-	-	-	-	-
Direct labour (m.d) (D-matrix)(Rs/day)								
DL 1 0-4	1.55	1.55	1.55	1.625	1.625	1.625	1.625	1.625
DL 2 4-5	0.28	0.28	0.28	0.313	0.313	0.313	0.313	0.313
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
DL 5 8-10	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
DL 6 ≥ 10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs(C_j in Rs)	33.48	33.26	32.84	34.86	35.19	34.38	35.90	36.13
Direct labour costs	13.54	13.54	13.54	13.95	13.95	13.95	13.95	13.95
Indirectlabour costs	10.65	10.04	9.75	11.19	11.53	10.70	12.43	13.44
Transport costs	9.29	9.68	9.55	9.72	9.71	9.73	9.52	8.74
Miscellaneous costs	-	-	-	-	-	-	-	-
Unit output of X_j	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m

(D.21.: cont.)

Technique X_j	12LBLP	PCHBLP	124DRF	11.53R	112DRF	1240RF	124URF	RBRCOF
Intermediate Inputs (A-matrix)	X_{65}	X_{66}	X_{67}	X_{68}	X_{69}	X_{70}	X_{71}	X_{72}
Cement (tonnes)	-	0.16325	0.0416	0.046	0.06405	0.0352	0.048	0.0376
Bricks (thousand)	0.494	-	-	-	-	-	-	0.027
Coarsesand (m^3)	-	0.92	.05785	.04888	.04463	.04895	.06675	0.0522
Finesand (m^3)	-	-	-	-	-	-	-	-
St.Aggregate(m^3)	-	-	0.1157	.09775	.08925	.0979	0.1335	0.1045
Unslaked lime(qntl.)	0.75	0.0828	-	-	-	-	-	-
Surkhi (m^3)	0.24	-	-	-	-	-	-	-
Stone at quarry(m^3)	-	-	-	-	-	-	-	-
Through&bond stones	-	-	-	-	-	-	-	-
Steel (Kg.)	-	-	7.20	8.13	8.90	18.79	5.60	5.93
Sandstone (sq.m)	-	-	-	-	-	-	-	-
Direct labour(m.d) (D-matrix)(Rs/day)								
DL 1 0-4	1.625	4.52	0.9501	1.0[illegible]6	1.07[illegible]	2.0737	0.8255	0.8851
DL2 4-5	0.313	-	0.0715	0.0633	0.0578	0.0605	0.0825	0.0908
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	0.43	-	0.7317	0.8234	0.9845	1.8889	0.5735	0.6079
DL 5 8-10	0.43	1.325	0.0117	0.0144	0.0945	0.0099	0.0135	0.0149
DL6 ≥ 10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs(C_j in Rs)	36.56	38.85	17.57	18.22	20.43	30.34	16.39	17.08
Direct labour costs	13.95	27.48	8.87	9.71	11.76	20.85	7.41	7.91
Indirectlabour costs	13.86	2.63	2.16	2.13	2.30	3.10	2.23	2.38
Transport costs	8.75	8.74	1.39	1.23	1.22	1.24	1.60	1.64
Miscellaneous costs	-	-	5.15	5.15	5.15	5.15	5.15	5.15
Unit output of X_j	1 cu.m	1 cu.m	1 sq.m	1 sq.m	1 sq.m	1 sq.m	1 sq.m	1 sq.m

(D.2.1: cont.)

Technique X_j Intermediate Inputs (A-matrix)	136BRF X_{73}	124FLG X_{74}	14BFLG X_{75}	16BFLG X_{76}	15RFLG X_{77}	15FFLG X_{78}	16CPLI X_{79}	117FL X_{80}
Cement (tonnes)	0.0352	0.15	0.1102	0.0725	0.08	0.08	0.036	0.0317
Bricks (thousand)	-	-	0.500	0.500	-	-	-	-
Coarsesand (m^3)	0.0752	0.178	-	0.3103	0.27	0.27	-	-
Finesand (m^3)	-	-	0.3103	-	-	-	0.1541	0.1541
St.Aggregate(m^3)	0.1504	0.356	-	-	-	-	-	-
Unslaked lime(qntl.)	-	-	-	-	-	-	-	0.1397
Surkhi (m^3)	-	-	-	-	-	-	-	-
Stone at quarry(m^3)	-	-	-	-	-	-	-	-
Through&bond stones	-	-	-	-	-	-	-	-
Steel (K.g)	5.42	-	-	-	-	-	-	-
Sandstone (sq.m)	-	-	-	-	10.0	10.0	-	-
Direct labour (m.d) (D-matrix)(Rs/day)								
DL 1 0-4	0.8252	1.89	1.794	1.794	0.70	3.52	0.8964	0.9396
DL 2 4-5	0.088	0.27	0.357	0.357	1.445	3.695	0.3132	0.3348
DL 3 5-6	-	-	-	-	-	-	-	-
DL 4 6-8	0.5564	1.35	1.080	1.08	-	0.320	-	-
DL 5 8-10	0.0144	-	-	-	3.10	12.60	0.81	0.81
DL 6 ≥ 10	-	-	-	-	-	-	-	-
Objective function coefficients								
Total costs(C_j in Rs)	16.42	26.19	35.05	35.53	42.12	148.32	13.20	14.20
Direct labour costs	7.32	17.33	15.52	15.52	36.61	142.81	11.74	11.99
Indirectlabour costs	2.23	4.59	10.32	9.98	1.13	1.13	0.45	1.13
Transport costs	1.72	4.27	9.21	10.03	4.38	4.38	1.01	1.08
Miscellaneous costs	5.15	-	-	-	-	-	-	-
Unit output of X_j	1 sq.m	10 sq m	10 sq m	10 sq m	10 sq.m	10 sq m	10 sq.m	10 sq.m

(D.2.1: cont.)

Technique X_j	129PLI	12LPLI	111PLI	16CPLE	117PLE	129PLE
Intermediate Inputs (A-matrix)	X_{81}	X_{82}	X_{83}	X_{84}	X_{85}	X_{86}
Cement (tonnes)	.02448	-	-	0.036	0.0317	.02448
Bricks (thousand)	-	-	-	-	-	-
Coarsesand (m^3)	-	-	-	-	-	-
Finesand (m^3)	0.1541	-	0.068	0.1541	0.1541	0.1541
St.Aggregate(m^3)	-	-	-	-	-	-
Unslaked lime (qntl)	.21744	.43344	.43344	-	0.1397	.21744
Surkhi (m^3)	-	0.1368	0.068	-	-	-
Stone at quarry(m^3)	-	-	-	-	-	-
Through&bond stones	-	-	-	-	-	-
Steel (Kg.)	-	-	-	-	-	-
Sandstone (sq.m)	-	-	-	-	-	-
Direct labour (m.d) (D-matrix)(Rs/day)						
DL 1 0-4	0.9396	0.9396	0.9396	0.8964	0.9396	0.9396
DL 2 4-5	0.3348	0.3348	0.3348	0.3132	0.3348	0.3348
DL 3 5-6	-	-	-	-	-	-
DL 4 6-8	-	-	-	-	-	-
DL 5 8-10	0.81	0.81	0.81	0.81	0.81	0.81
DL 6 ≥ 10	-	-	-	-	-	-
Objective function coefficients						
Total costs(C_j in Rs)	14.55	15.83	15.59	13.20	14.20	14.55
Direct labour costs	11.99	11.99	11.99	11.74	11.99	11.99
Indirectlabour costs	1.46	2.81	2.57	0.45	1.13	1.46
Transport costs	1.10	1.03	1.03	1.01	1.08	1.10
Miscellaneous costs	-	-	-	-	-	-
Unit output of X_j	10sq.m.	10sq.m	10sq.m	10sq.m	10sq.m	10sq.m.

D.2.2. ROAD CONSTRUCTION

Technique X_j	LABEXC	CAPEXC	TRENSG	SOLING	148SBC	WBMSBC	111SBC	111SBP	WBMCDM	PRCMT	SLCOAT	124WCT	IUZWCT
Intermediate Inputs (A matrix)	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
Cement (tonne)	-	-	-	-	0.17	-	-	-	-	-	-	0.32	0.256
Coarsesand (m^3)	-	-	-	-	0.47	-	-	-	-	-	0.75	0.445	0.445
Finesand (m^3)	-	-	-	-	-	-	0.19	0.19	-	-	-	-	-
Stoneaggregate (m^3)	-	-	-	-	0.89	-	0.94	0.94	-	3.0	-	0.85	0.85
Lime (quntl.)	-	-	-	-	-	-	1.204	1.204	-	-	-	-	-
Surkhi (m^3)	-	-	-	-	-	-	0.19	0.19	-	-	-	-	.06106
Bitumen (tonne)	-	-	-	-	-	-	-	-	-	0.267	0.096	-	-
Diesel (litres)	-	-	0.972	0.108	-	0.59	-	-	0.59	2.0	1.08	-	-
Moorum (m^3)	-	-	-	-	-	0.4	-	-	0.4	-	-	-	-
Soling stone (m^3)	-	-	-	1.15	-	-	-	-	-	-	-	-	-
St.metal (WBM) (m^3)	-	-	-	-	-	1.46	-	-	1.46	-	-	-	-
Coal (quntl.)	-	-	-	-	-	-	-	-	-	0.534	0.192	-	-
Direct-capital Equip. (machine days)													
Road-roller	-	-	0.054	0.006	-	0.033	-	-	0.033	0.11	0.06	-	-
Boiler	-	-	-	-	-	-	-	-	-	0.15	0.05	-	-
Concrete mixer	-	-	-	-	0.05	-	0.05	0.05	-	-	-	0.05	0.05
Hot-mixplant	-	-	-	-	-	-	-	-	-	0.04	0.01	-	-
Pick-axe	0.027	-	-	-	-	-	-	-	-	-	-	-	-
Shovel	0.108	-	-	-	-	-	-	-	-	-	-	-	-
Forks	0.027	-	-	-	-	-	-	-	-	-	-	-	-
Wheel-barrow	0.027	-	-	-	-	-	-	-	-	-	-	-	-
Bull-cart	0.054	-	-	-	-	-	-	-	-	-	-	-	-
Plough	0.0108	-	-	-	-	-	-	-	-	-	-	-	-
D7 Bulldozer	-	0.0147	-	-	-	-	-	-	-	-	-	-	-
Thickwire brush(no..)	-	-	-	-	-	-	-	-	-	0.11	0.05	-	-
Soft brush(nos.)	-	-	-	-	-	-	-	-	-	0.32	0.12	-	-

D,2,2 (Cont.)

Technique X_j	LABEXC	CATEXC	PIEPSG	SOLING	148SBC	WBMSBC	111SBC	111SBP	WBMCDM	PRCRPT	[illegible]	124WCT	TUZWCT
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
Direct Labour(m.d) (D matrix)Rs./day													
DL1 0-4	0.225	.0053	8.064	1.056	1.50	0.553	1.86	1.86	0.553	10.38	3.38	1.50	1.50
DL2 4-5	0.0072	-	-	0.18	0.31	0.26	0.49	0.49	0.26	0.19	0.12	0.31	0.31
DL3 5-6	0.0[illegible]8	-	-	-	-	-	-	-	-	-	-	-	-
DL4 6-8	-	0.0147	-	-	0.05	-	0.05	0.05	-	-	-	0.05	0.05
DL5 8-10	0.0036	-	-	-	0.05	-	0.05	0.05	-	0.19	0.06	0.05	0.05
DL6 ⩾ 10	-	-	-	-	-	-	-	-	-	-	-	-	-
Objective function coefficients													
Total costs(C_j in Rs)	1.20	0.12	28.29	14.35	27.29	16.75	33.40	33.40	16.75	84.94	20.85	29.63	30.27
Direct labour costs	1.20	0.12	28.22	4.54	7.50	3.16	9.60	9.60	3.16	38.90	12.93	7.50	7.50
Indirect labour cost	-	-	-	2.20	9.73	2.80	15.36	15.36	2.80	26.17	0.60	10.76	10.36
Transport costs	-	-	0.07	7.61	10.06	10.79	8.44	8.44	10.79	19.87	7.32	10.21	11.25
Miscellaneous costs	-	-	-	-	-	-	-	-	-	-	-	1.16	1.16
Unit output of X_j	1cu.m	1cu.m	100sq.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	1 cu.m	100sq.m	100sq.m	1 cu.m	1 cu.m

D.3: Information on prices for building and road construction: The following data correspond to the prices, as prevailing in 1972, of different intermediate inputs, primary resources and the capital equipment required in the construction of buildings and roads:

Prices prevailing in 1972	Rs.
Cement per tonne	227.00
Coarse sand per m^3	19.30
Fine sand per m^3	4.10
Stone aggregate per m^3	16.48
Lime per quintal	13.28
Surkhi per m^3	25.50
Bitumen per tonne	692.00
Diesel per litre	0.88
Moorum per m^3	5.80
Soling stone per m^3	9.70
Stone-metal (for WBM work) per m^3	9.85
Bricks per thousand	56.00
Stone at quarry per m^3	7.35
Through & bond stones per tonne nos.	4.20
Steel per Kg.	1.20
Sandstone per sq.m.	10.80
Electricity per kwh	0.20
Coal per tonne	35.81
Limestone per tonne	8.93
Gypsum per tonne	11.94
Clay per tonne	2.60
Manganese ore per tonne	44.70
Dolomite per tonne	16.40

Prices of the capital equipment used in Road Construction	Rs.
Diesel Road roller each	85000.00
Coal-tar boiler each	5000.00
Concrete Mixer each	10000.00
Hot mix plant each	99000.00
Pick-axe each	16.00
Shovel each	18.00
Wheelbarrow each	400.00
Bull-cart each	1500.00
Plough each	50.00
D7 Bulldozer each	220000.00
Thickwire brush each	2.25
Soft brush each	2.00
Fork each	12.00

BIBLIOGRAPHY

Acharya, S.N. (1974) - "Fiscal-Financial Intervention, Factor prices and factor proportions : A Review of Issues", mimeo. IBRD, DED.

Agarwal, C.V. (1965) - "Chemistry of Engineering Materials". Tara Publications.

Aigner, D.J. and Chu, S.F. (1968) - "On Estimating the Industry Production Function". The American Economic Review.

Arrow, K.J. et.al. (1959) - "Substitution Between Capital And Labour". Stanford University.

Arrow, K.J. and Chenery, H.B, etc. (1961) - "Capital Labour Substitution and Economic Efficiency". The Review of Economics and Statistics.

Bardhan, P.K. (1964) - "A New Production Function" - The Economic Weekly.

―――――― (1967) - "On Estimation of Production Functions from International Cross-section Data". The Economic Journal.

Baumol, W.J. (1973) - "Economic Theory and Operations Analysis". Prentice-Hall, India.

Behari, B. (ed.) (1975) - "Appropriate Technology for Balanced Regional Development". Vol.I and II, Govt. of India, Ministry of Industrial Development, (Appropriate Technology Cell), New Delhi.

Bhalla, A.S. (1964) - "Investment Allocation and Technological choice - A case of Cotton Spinning Techniques". The Economic Journal.

―――――― (1965) - "Choosing Techniques : Handpounding Vs. Machine Milling of Rice : An Indian Case". Oxford Economic Papers.

Boon, G.K. (1964) - "Economic Choice of Human and Physical Factors in Production : An attempt to measure the Micro-economic and Macro-economic Possibilities of the Variation in Factor Proportions of Production". Amsterdam, North-Holland.

Brown, M. (ed) (1967) - "The Theory and Empirical Analysis of Production". New York, NBER and Columbia University Press.

Burmah-Shell Oil Storage and Distributing Co. of India Ltd. - "Bituminous Road Construction".

Central Public Works Department (1972) - "Delhi Schedule of Rates". Govt. of India.

__________(1972) - "Analysis of Rates for Delhi". Vol.I to IV. Govt. of India.

Central Road Research Institute (1964) - "Puzzolanic Clays of India, Their Industrial Exploitation and Use In Engineering Works". Road Research Special Reports No.1.

Central Statistical Organization - "National Accounts Statistics" 1960-61 to 1972-73.

__________ - "Index Numbers and Wholesale Prices in India, January 1968 to December 1972.

Central Water and Power Commission (1951) - "Handbook of Earth Moving Machinery", Govt. of India.

__________(1956) - "Report of the Rates and Costs Committee". Govt. of India.

__________(1959) - "Report of the Construction Plant and Machinery Committee". Govt. of India.

Chatterjee, et.al. (1963) - "Choice of Techniques in Mustard Oil Industry" No.280 , Studies in National Development Planning, Indian Statistical Institute, Calcutta.

Chenery,H.B. (1949) - "Engineering Production Functions". Quarterly Journal of Economics.

__________(1953).- "Process and Production Functions from Engineering Data". In . Leontif et.al. (1953).

__________(1961) - "Comparative Advantage and Development Policy". American Economic Review.

Chenery,H.B. and Clark,P.G. (1959) - "Interindustry Economics". John Wiley and Sons, Inc. New York.

Cromer,C. (1975) - 'Labour Intensive Construction Methods and Unemployment : World Bank Study on Substitution of Labour and Equipment in Civil Construction". Economic and Political Weekly.

Concrete Association of India (1963) - "Elementary Handbook of Concrete House Construction".

__________(1965) - "Guide to Good Concrete Road Construction".

__________(1966) - "Low Cost Soil Cement Houses".

__________(1971) - "Simple Re-inforced Concrete Design Tables".

__________(1973) - "Pre-cast Concrete Houses".

__________(1973) - "Re-inforced Concrete Designers' Manual".

__________(1973) - "Cost of Road Construction". The Indian Concrete Journal.

Department of Scientific and Industrial Research (1962) - "Bituminous Materials in Road Construction". Her Majesty's Stationary Office. London.

Dorfman,R. and Samuelson,P.A. and Solow,R.M.(1958) - "Linear Programming and Economic Analysis". McGraw-Hill Kogakusha.

Frisch,R. (1935) - "The Principle of Substitution - An Example of its Application in the Chocolate Industry". Nordish Tidsskrift For Teknisk Økonomi.

Furuboth,E.G.(1965) - "Engineering Data and The Production Function". The American Economic Review.

Ghosh,M.N.(1956). - "Choice of Technique". The Economic Weekly.

Government of India (1972) - "Economic Survey".

Hirsch,W.Z.(1952) - "Manufacturing Process Functions". Review of Economics and Statistics.

__________(1956) - "Firm Progress Ratios". Econometrica.

Indian Institute of Public Opinion (1973) - "The Growth of the Cement Industry". Monthly Commentary on Indian Economic Conditions.

Indian Standards Institution (1957) - "Code of Practice for Plain and Re-inforced Concrete for General Building Construction".

__________(1965) - "Indian Standard Code of Building Bye-Laws".

__________(1970) - "National Building Code of India".

International Bank for Reconstruction and Development (1974) - "Study of the Substitution of Labour and Equipment in Civil Construction". Staff working paper No.172.

Irwin,G.W.(1975) - "Roads and Redistributions". International Labour Office. Geneva.

Jaikrishna and Jain,O.P.(1959) - "Plain and Re-inforced Concrete". New Chand and Brothers; Roorkee.

Joglekar,S.K. (1973) - "Housing'25th Anniversary of Independence Series- Publications Division, Ministry of Information and Broadcasting, Govt. of India.

Johansen,L.(1972) - "Production Functions : An Integration of Micro and Macro, Short-run and Long-run Aspects". North Holland.

Kannan,K.P. and Spence,R.J.S. (1975) - "A Social cost Approach to Choice of Technology in Building Construction". Economic and Political Weekly.

Khadi,and Village Industries Commission (1966) - "Working of the Experimental Improved Lime-Kiln".

Khanna,P.N.(1974) - "Indian Practical Civil Engineers' Handbook".

Kurz, M. and Manne, A.S. (1963) - "Engineering Estimates of Capital - Labour Substitution in Metal Machining". The American Economic Review.

Lal,D. (1973) - "Men or Machines - A Phillippenes case study of Labour - Capital Substitution in Road Construction". International Labour Office, Geneva.

Lal, R.N.(1975) - "Capital Formation in India". Economic Times.

Lave,L.B.(1966) - "Engineering Production Functions and Capital Labour Substitution in Metal Machining: A comment". The American Economic Review.

Leontif, W. et.al. (1953) - "Studies in the Structure of the American Economy". New York, Oxford University Press.

Manne,A. and Markowitz, H. (ed) (1963) - "Studies in Process Analysis". New York.

Mathur,G.C.(1960) - "Brick-Making" - National Buildings Organization.

___________(1961) - "Building Lime" Lime Manufacturing Association of India, New Delhi

____________(1972) - "Economic Factors and Their Impact on Housing Construction Costs". Paper submitted at the seminar on Economics of Housing in National Development at Ootacamund.

____________(1972) - "Role of self-help Housing in National Development". Paper submitted at the seminar on Economics of Housing in National Development at Ootacamund.

____________(1973) - "Importance of Building Industry in the Context of National Development Plans - Role of National Buildings Organization". Unpublished. National Buildings Organization, New Delhi.

____________(1973) - "Prefabrication and Industrialization of the Building Industry". Unpublished, National Buildings Organization, New Delhi.

Mayor,T.H. (1969) - "Some Theoretical Difficulties in the Estimation of the Elasticity of Substitution from Cross-section Data". Western Economic Journal.

Meier,G.M. (1970) - "Leading Issues in Economic Development". Studies in International Poverty . Oxford University Press.

Minhas, B.S. (1958) - "International Comparison of the Relationship Between Labour Inputs and Wage Rates in Manufacturing Industry". Stanford University.

____________(1963) - "An International Comparison of Factor Costs and Factor Use". Amsterdam. North Holland.

Morawetz,D. (1974) - "Employment Implications of Industrialization in Developing Countries : A Survey". The Economic Journal.

Morley,A. (1956) - "Theory of Structures". Longmans, Green and Co. London, Etc.

Myrdal, G. (1968) - "Asian Drama". London, Penguin Press.

____________(1970) - "Challenge of World Poverty" : A World Anti-Poverty Programme in Outline'. London, Penguin Press.

Narasimhan,N.V.A. (1971) - "Impact of Construction on Employment" in Employment and Unemployment Problems of the Near East and South Asia, Vol.II by R.G.Ridker and H.Lubeu(ed.)

Narayana, N.S.S. (1975) - "Engineering Production Function for Building Construction". Unpublished. paper submitted to the Indian Econometric Conference, New Delhi.

National Building Organization (1961) - 'Report of the Experts Committee on Economy in the use of Cement in Building Construction".

__________(1966) - "Handbook for Building-Engineers In Metric System".

National Council for Applied Economic Research (1974) - 'Employment in Road Transport and Road Construction, NCAER, New Delhi.

National Sample Survey (9th round), July 1964 to June 1965. Tables with Notes on Housing Condition, No. 195.

Nerlove, M. (1963) - "Returns to Scale in Electricity Supply", In : Measurement in Economics : studies in mathematical economics and econometrics in memory of Yehuda Grunfield, (ed.) by C.F.Christ et.al., Stanford, California, Stanford University Press.

__________(1965) - "Estimation and Identification of Cobb-Douglas Production Functions". Amsterdam, North Holland.

O'Herlihy, C.St.J.(1972) - 'Capital-Labour Substitution and The Developing Countries : A Problem of Measurement". Bulletin of the Oxford University Institute of Economics and Statistics.

Parikh, K.S.(1973) - "Cities For the Poor", Times of India.

__________et.al.(1974) - "Performance Approach to Cost Reduction in Building Construction". Report of the Expert Committee, Govt. of Kerala.

Planning Commission - "Basic Statistics Relating to the Indian Economy" (1950-51 to 1970-71). Govt. of India.

Raj, K.N. (1956) - "Small Scale Industries : Problem of Technological Change - The Economic Weekly.

Rao, A.V.R. (1970) - "Simple Brick Making Machines". Journal of the National Buildings Organization.

Rao, K.L. (1958) - "Calculation, Design and Testing of Reinforced Concrete". London, Pitman.

Registrar General and Census Commissioner (1972) - "Pocket Book of Population Statistics". Govt. of India.

__________(1974) - "Population of India". Govt. of India.

Robinson, Joan (1956) - "The Choice of Technique". The Economic Weekly.

______________(1964) - "Factor Prices not Equalised". Quarterly Journal of Economics or Collected Economic Papers (1965) Vol.III.

Rudra, A. (1956) - "The Problem of Technological Choice". The Economic Weekly.

__________(1969) - "Measurement in Economics". Bombay Allied.

Sachs, Ignacy (1970) - "Selection of Techniques : Problems and Policies for Latin America". Economic Bulletin for Latin America.

Saluja, M.R. (1971) . "Capital-Output Ratios in Indian Manufacturing Industries". Unpublished paper submitted to the Indian Econometric Conference, Hyderabad.

Sandesara, J.C. (1969) - "Size and Capital Intensity in Indian Industry".

Science Today (1975) - "Cement - A Special Study". A Times of India Publication.

Sen, A.K. (1960) - "Choice of Techniques : An Aspect of the Theory of Planned Economic Development". Oxford.

__________(1969) - "Choice of Technology : A Critical Survey of A class of Debates in Planning for Advanced Skills and Technologies". New York, Vienna. UNIDO. Industrial Planning and Programming Series No.3.

__________(1973) - "Employment Policy and Technological Choice". Mimeo. London School of Economics.

Singh, Gurucharan (1973) - "Handbook on Civil Engineering".

Smith, V.L. (1961) - "Investment and Production". Cambridge, Mass. Harvard University Press.

Srinivasan, T.N. (1962) - "Investment Criteria and Choice of Techniques of Production". Cowles Foundation Paper No. 177. Yale Economic Essays.

__________(1969) - "Econometrics". Frontier.

Subbaraju, Bh. and Dhir, M.P. (1959) - "Economics of Highway Pavement Design". Road Research Papers No.37, Central Road Research Institute of India, New Delhi.

Sutcliffe, R.B. (1971) - "Industry and Underdevelopment".

Turvey, R. (1971) - "Public Enterprise". Penguin Edition.

United Nations, ECAFE (1961) - "Criteria for Allocating Investment Resources Among Various Fields of Development in under-developed countries". Economic Bulletin for Asia and Far East.

__________(1961) - "Earthmoving By Manual Labour and Machines". Flood Control Series No.17.

Walters, A.A. (1963) - "Production and Cost Functions : An Econometric Survey". Econometrica.