OPTIMISING BRICKWORK COSTS IN A COMPLEX AND CHAOTIC ENVIRONMENT

By

W.V.K.M. Abeysekera and A. Thorpe

Abstract:

Sri Lankan brickwork is characterised by a wide variation in brick and joint sizes. There appears to be little knowledge on how these variations impact on costs and strategies needed for coping with issues related to costs. The environment within such decisions have to be treated as ‘complex’ and ‘chaotic’. This study advocates the use of ‘decision rules’ to cope with such situations. These rules have been developed by identifying ‘intrinsic’ cost features of brickwork and revolves around two variables, viz. the ‘bricks to mortar ratio’ and the ‘cost polarity’ of bricks and mortar. Two principle features of these ‘decision rules’ are ‘universality’ (global validity) and ‘time independence’ (perpetual validity). These rules lead to the concept of ‘cost homogeneity’ in brickwork (despite the heterogeneity of the material prices) wherein the need to control joint sizes cease to exist. In the absence of ‘cost homogeneity’, the solutions advocated are ‘dynamic’ and not ‘static’ to cope with emerging scenarios. It is argued that these ‘decision rules’ are a simple and implementable approach for coping with chaotic and complex situations.

Keywords: brick, brickwork, chaos, cost, complexity, decision rules, estimating

1.0 Introduction

Building with burnt clay bricks is part of Sri Lanka’s engineering culture. To date, bricks produced by the island’s cottage industry have remained the principal building element in the construction of walls. These walls, plastered on both sides, are used mainly as infills or partitions in reinforced concrete buildings except for walls in single storey and two storey buildings carrying light loads.

Neither bricks nor walls in Sri Lanka conform with standard sizes and vary widely. Brickwork joints too vary, with significant departures from the norms of other organised construction industries (Abeysekera, 1987). These variations result in many problems in the industry in what can be described as a disordered or chaotic environment. With material costs far in excess of our, the status-quo continues without regard to impact on time and costs (Abeysekera, 1997).

In an increasingly commercial world, it is not surprising that issues connected with costs take centre place in triggering decisions. However, with regard to Sri Lankan brickwork, there appears to be little knowledge on how the variables such as brick size, joint sizes and wall width impact on costs. This Paper focuses on the impact of these variables in the search of strategies for coping with ‘chaos’ in Sri Lankan brickwork.

Brickwork is an activity which is extensively sub-contracted both in the formal and informal sectors of the construction industry. These labour only ‘trade’ sub-contractors do not differentiate their rates either with respect to the size of the brick or with respect to the wall thickness (Munasinghe, 1996). It appears, therefore, that the impact of study variables such as joint sizes, brick size and wall thickness are not significant enough to induce clients or contractors to qualify their rates accordingly.

Otherwise, the situation at hand is complex. The chaos in the study variables, the prices of materials and labour, their instability, contractual provisions, the arrangements for procurement, procedures for estimating, the emerging future, goals of decision makers and the like, all come into play when decisions have to be made with respect to costs. How, then can contractors and consultants cope with such situations?

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One approach would be to compute total costs in each and every situation to assess their impact using computer models. However, it would be of much greater value, if it was possible to identify 'intrinsic' cost related features which would facilitate this process and in turn make decision making much simpler and logical in a complex environment which is constantly changing.

2.0 The Emerging Future and Price Movements

2.1 Price Movements

The publication of cost indices of basic construction materials was undertaken by the Central Bank of Sri Lanka until the late 1980s, whose database was completely destroyed due to the civil disturbances in 1995. Fortunately, the work of the Central Bank was duplicated by the Statistics Unit of the Programming Division in the Ministry of Housing and Construction which published a 'Statistical Bulletin' giving similar information. With ICTAD commencing its construction cost database in 1990, the work of this unit (including staff) were assigned to ICTAD. Unfortunately, as a result of these developments, some of the statistical bulletins relating to the pre-1990s were lost. However, with the information available in these statistical bulletins, ICTAD's database and other sources, a time series was constructed in order to obtain a general picture of the movement of material prices in and around Colombo.

The rapid rise in the prices commenced after the liberalisation of the economy in 1977. It continued until 1994 when the situation changed significantly, from a rapid growth to a decline with the change of government in late 1994.

2.2 Issues Related to Cement

Currently, there is only one type of cement manufactured in Sri Lanka, which is commonly referred to as ordinary Portland Cement or OPC (Type 1). The demand is met through local manufacture and imports to supplement shortfalls. Though imported cement is cheaper it is considered to be of dubious quality. The prices, especially during the last two to three years have been volatile with significant fluctuations (as much as 40%) due to imbalances in supply and demand.

In view of the high price of OPC cements, masonry cement was introduced to the local market in April 1979 at an ex-factory price of Rs. 19.50. At this time OPC was marketed at Rs. 45.00 per 50 kg. bag. (Data for Costing, 1980, p 2.7; Chandrakeerthi, 1980, p.36). However, after a few years in use, it was withdrawn from the market to eliminate adverse consequences adulterating expensive and stronger OPC cement with cheaper and weaker masonry cement. However, some Government officials felt that as importation of masonry cement has not been banned by the Government, it could be imported, if necessary. Neither the private sector nor the government sector has taken any initiatives in this regard (i.e. to manufacture or import) to either import cheaper masonry cements or similar cements (Kulasinghe, 1995, Bogahawatte, 1996). For example, in China the standard on cement was redefined to recognise six different quality levels; it is claimed that over three-quarters of their needs are met by small scale, rural based, labour-intensive appropriate plants producing low-price cement (Kaplinsky, 1992).

However, in Sri Lanka, the status-quo prevails, in a state of indeterminacy, especially with respect to a suitable type of cement for brickwork. The future is uncertain due to number of reasons with the possibility of significant changes both in quality and price viz. the possibility of cheaper substitutes, instability in the prices due to shortages (or even 'pseudo' shortages); price changes due to changes in exchange rates; government's policy on import duties, and changes in the global environment.

![Price Movement of Cement, Sand and Bricks](image)

Fig. 9.1: General movement of material prices

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2.3 Issues related to Sand

The traditional source of sand supply for construction has been the rivers from which sand is 'harvested'. There are four different types of sand used in industry, viz. coarse, medium, fine, and very fine; prices do not generally vary with type. Purchasing sand from the open market is problematic and has an impact on the 'real' price of sand due to problems of bulking and ploys employed by suppliers to inflate the volume of sand (Abeysekera, 1996). To a large extent sand is a 'free' resource (being harvested from rivers). As such haulage accounts for the largest component of its cost. Hence, the extraction levels at 'harvesting' sites closest to demand centres (cities and suburbs) have been heavy. Sand 'harvesting' is a labour intensive operation and mechanical mining is rare. Nevertheless, fears have been expressed that 'continued extraction of sand ... at present rates would pose severe environmental problems with respect to the coastal and river regimes' (National Sand Study of Sri Lanka - NSS, Phase 1, 1992, p. 1.2). Not surprisingly, efforts have been made to regulate sand mining (especially during the last decade) though monitoring and enforcement has been weak.

Suggestions have been made to explore alternative sources (NSS, p. 2.8), especially sustainable sources (Aggregate Production Study, 1993, p.56), and to maintain a balance between abstraction of sand and its production from river basins. These attempts would no doubt have a bearing on price and any attempt to forecast prices in the years ahead (i.e. in the long term) would be futile in such an environment.

However, to forecast price changes in the short term, for example due to weather patterns is less difficult. The sand prices increase during monsoonal periods when rivers are too deep for sand mining. The months of May-June, and especially the months of October-November are periods when such increases are likely to take place. In fact, these are periods where the elasticity of the 'price hike' is checked by the suppliers with attempts to accelerate escalation, and then resist deceleration (depending on demand) when the supply picks up. A common practice adopted by financially strong suppliers is to stockpile sand during the dry periods and sell it at a higher price during wet periods with a double advantage from the effect of bulking and sharp rise in prices during rainy periods (Abeysekera, 1996a); However, similar attempts by construction contractors (i.e. to beat price hikes by stockpiling) are infrequent, perhaps due to restrictions in the availability of space at sites, cash flow constraints and due to price reimbursement clauses in formal construction contracts. However, as to what may happen in the long term, is largely unpredictable for reasons given herein.

2.4 Issues related to Handmade Bricks

Bricks used in Colombo may be divided into four broad groups depending on size viz. small, large, standard and extra-large (see Appendix 1). Of these, there is a ready market for small size bricks from the 'Kochchikade' area, being cheaper and freely available.

Like sand, clay mining is essentially a labour intensive operation (though not free) in almost all parts of the country except in areas around Kochchikade (where small size bricks are produced). The main source of supply of bricks to Colombo has been from this area; not surprisingly, the mining process has become mechanised to meet the demand for clay, not only for bricks but for tiles as well. To mitigate environmental impacts of such mechanised activities which results in drastic change in the environment over a very short period, a mechanism to be developed to restore the clay mines to the state before mining. The new Mines and Minerals Act No. 33 of 1992 explicitly identifies mining of clay for building materials as a mineral resource requiring a royalty payment to the state. Accordingly, 'excavators' have to obtain an industrial mining licence with the posting of a mine restoration bond. The impact of such a bond and the cost of refilling has been estimated to be around 19-28.5% (Ranasinghe, 1996). The rapid increase in the prices of bricks since 1993/94 (Fig. 1) is considered to be due to this new development and the floods in 1993/94. However, price increase stabilised after the change of government in 1994, with a decline from around April 1995 due to low demand - a situation, which may lead to a further decline in the size of the brick!

The situation is somewhat different with respect to larger Kduwela bricks (being produced in a different river basin); clay mining is essentially a manual activity in this area. As the pits are shallow there does not appear to be a need for mine restoration bonds as the impact on the environment is not as severe as in mechanical mining. Thus, there is a difference in the factors of production of the two principal areas supplying bricks to Colombo. A question that arise therefore is, whether it would ever be possible to have one standard size (as laid down in the SLS for bricks), when two areas with different factors of production supply the same type of product, differentiated by size.

The standard brick, larger in size than the Kochchikade and Kduwela bricks (though not of the 'standard size' as given in SLS 39), is expensive and is in short supply, whilst the extra-large brick mentioned earlier is rarely used.
Production difficulties (Bogahawatte, 1985), differences in factors of production in different areas (Abeysekera, 1990), regional variations in prices, and many more, makes forecasting long term prices an almost impossibility, especially in an emerging future.

2.5 The Need for Dynamic Approaches

These discussions highlight the difficulties of predicting the future especially the long term future in view of the afore-mentioned facts which clearly identifies the uncertainty that prevails. In such an environment, it is logical to presume that static solutions (say a standard joint size) cannot be cost effective. An examination of the past would provide supporting evidence as shown in the ensuing sections. The dynamics of the situation is such that many factors affect costs and they change with time. Furthermore, they vary from site to site, region to region and within sites as well and the situation is indeed complex. In a complex environment such as this, it is reasonable to doubt the efficacy of static solutions; in fact, such solutions need to be rejected in favour of adopting a dynamic approach to coping with the chaos in costs.

3.0 The Dynamics of Material Costs

3.1 In general

Discussions with estimating personnel in contractors’ organisations revealed a number of factors which affect material costs. Amongst these were, locality of project, wastage of materials, contractual provisions for reimbursement of costs due to price fluctuations, risks involved, site conditions, proximity to material sources, capacity of conventional material sources to cope with demand, attitude of consulting engineers and architects, shapes/lengths of brick walls and project duration. However, none of the contractors mentioned the problems associated with bulking of sand at point of sale and eventual use (See section 3.13.5); Whilst large companies appear to take into account such factors, discussions with medium to small construction companies (i.e. Grade 3 and below) revealed that at times various ‘market oriented strategies’ were adopted for pricing.

In contrast, discussions with consulting engineering/architectural firms revealed that they rarely, if ever, took into account the ‘specifics’ related to brickwork costs; instead their estimates were based on a generalised set of rates to cater for a wide variety of situations; The ‘Data for Costing’ published by the Dept. of Irrigation, the Building Schedule of Rates (BSR) published by the Ministry of Local Government, Housing & Public Utilities, the Schedule of Rates published by the Plantation Housing and Social Welfare Trust (PHSWT) are documents with such an approach to costing. Obviously, these highly generalised estimates are of dubious accuracy.

3.2 This Study

3.2.1 The Total Cost of Materials

The method adopted to compute the total cost of materials per cubic metre of wall is given below:

\[
\text{Total cost of materials} = \text{Volume of mortar x unit volume cost of mortar} + \text{Volume of bricks x unit volume cost of bricks}
\]

Volume of mortar referred to herein is not ‘volume in place’ but the ‘volume after mixing’ of mortar (i.e. before filling into joints); Accordingly, the unit volume cost of mortar must necessarily refer to this ‘state’ of mortar.

3.2.2 Unit Volume Cost of Mortar & Bricks

The cost of a unit volume of mortar depends on mix proportions. If the mortar mix is 1:N (i.e. for every portion of cement, N portions of sand), it could be expressed as:

\[
\left\{\frac{\text{DF}}{1 - (\text{Wm}/100)}\right\} \times \text{EPct} \times \left\{\frac{\text{DF}}{1 - (\text{Wm}/100)}\right\} \times \text{EPs}
\]

where,

\[
\text{DF} = \text{Dry factor (volume of sand/volume of mortar)}
\]

\[
\text{Wm} = \text{Percentage of wastage in mortar;}
\]

\[
\text{EPct} = \text{Effective price of cement per unit volume;}
\]

\[
\text{and}
\]

\[
\text{EPs} = \text{Effective price of sand per unit volume}
\]

If the wastage of bricks, cement and sand is Wb, Wct and Ws respectively, and the bulking of sand at source is BF, then the effective prices of bricks, cement and sand could be shown to be equal to

\[
\frac{\text{Pb}}{1 - \text{Wb}/100}, \frac{\text{Pct}}{1 - \text{Wct}/100} \text{and} \frac{\text{Ps}}{1 - (\text{BF}/100)},
\]

respectively. Pb, Pct and Ps are the purchase price of bricks, cement and sand delivered to site. Long term averages quoted by the bricklayers were used for Wb, Wm, Wct and Ws. (For the purpose of this study values of 9.27%, 1.59%, 0.13%, 7.06% were used; Abeysekera, 1997.) However, in practice, these values have to correspond with the situation at hand.

3.3 The Impact of Mortar Mixes

Many different types of mortar may be used for brickwork. For example, in the Code of Practice for
Structural Use of Masonry (i.e. BS 5628), four categories of mortar are specified, based on strength and serviceability requirements with appropriate mixes (Table 1, p. 4). It is argued that, issues related to serviceability, such as resistance to rain water penetration, ability to accommodate movements, resistance to frost attack etc. are not of relevance with local brickwork; for example, walls are plastered, temperature cycle is insignificant and there is no frost being a tropical country. Nor is strength important of significant importance to this study as walls are non-load bearing or lightly loaded. As such cement lime mixes as weak as 1:2:9 or cement sand mixes as weak as 1:8 may well be used. However, lime is rarely used as a brickwork mortar mainly due to its high cost though it may become popular once again if lime mining is carried out cost effectively. (Kulasinghe, 1996)

The types of mortar mixes used in Sri Lanka has varied over time, moving from lime-sand mortars to cement-sand mortars. Discussions revealed that it was common to use a 1:5 lime sand mix in the beginning of this century. During the 1930s when cement was introduced to Sri Lanka the use of cement-lime-sand mortars had emerged (Kulasinghe, p.16), not necessarily out of economic considerations. In the more recent past there has been a shift towards the use of cement sand mixes varying from 1:5 to 1:10, often using 1:5 or 1:8 for single brick thick walls. Thus, what is observed is that the type of mortar used had changed with an emerging future. This phenomenon is not a new experience, as examination into mortars used in ancient construction show similar lessons (Silva, 1982); history repeats itself.

Furthermore, an examination of the ICTAD Specification for Buildings Works (Sri Lanka) show that mortars for brickwork are specified according to the thickness of the wall (differentiating only between half brick thick walls and others); and on whether the wall is below or above ground level. The weakest mortar mix permitted is 1:8 cement sand or 1:2:9 cement, lime and sand with OPC cements, and 1:5 with masonry cements. In fact, the strength of mortar is of little importance to brickwork, as it is the crushing strength of the unit and its size that matter (See Table 2 of BS 5628: Part 1: 1978, p. 7). For example, in India, cement sand mixes as weak as 1:9 is being used even in situations of heavy loading in the order of 60-80 tonnes/sq.m. (Khanna, p. 12/14); For medium loading conditions, cement is not even used. In fact, mud mortar (which is cheap) is used with ‘second class’ bricks (Vazirani, p. 47). Similar mortars have been mooted for use in Sri Lanka too as a means of reducing cement consumption (Kulasinghe, Chairman, Central Engineering Consultancy Bureau, 1996, p.15); but as to whether society at large would accept such usage is questionable.

Thus, once again, what transpires is the uncertainty of the future, not only in relation to material prices, but on mortar mixes as well; literally, what is used today may not be used tomorrow, not necessarily out of rational considerations. Thus, prescribing static solutions to an emerging and unpredictable future is too rigid an approach to be pursued successfully.

3.4 The Instability and the Sensitivity of Material Costs

The past has lessons for the future as mentioned earlier. It also provides evidence of foregone opportunities and the like. As such, it is useful to examine, the movement of total material costs. Accordingly, data relating to the past two decades were examined and in doing so three scenarios were considered:

Scenario 1: Walls with standard joint sizes, i.e where the bed joint, the cross joints of the header and stretcher courses were all taken as 10 mm each. (i.e. BMT= TH = TS = 10 mm);

Scenario 2: Walls with average joint sizes, using average values observed with respect to mortar consumption walls (i.e. BMT= 17.11; TH = 20.87; TS = 14.67 mm; Abeysekara, 1996b)

Scenario 3: Walls with large joint sizes, using maximum values observed with respect to mortar consumption walls (i.e. BMT= 25.49, TH= 25.41, TS = 37.43 mm; Abeysekara, 1996b)

The cost indicators plotted in Fig. 2 were computed by dividing the cost of the wall by the cost of ‘base’ walls relating to Scenario 1. Two different mixes were also considered, viz. 1:5 and 1:10.

Consider walls with the 1:5 mixes. The relevant plots show that walls with large joints have always been costlier except in 1994. It has peaked in 1982 with a cost difference of around 20%. Thus, if a contractor used large joints instead of small joints, an opportunity for reducing costs by as much as 20% would have been lost!

However, walls with a mix of 1:10 mix show somewhat of a contrasting picture as larger joint sizes would have been cheaper except for during the period 1979-1987. The cost advantages of using larger joints had peaked in 1994 and has reduced thereafter. Thus,
if in 1994, a consultant imposed the use of smaller joints, it would have been over costly. The situation would have been the same in the pre 1979 period.

Thus, it is seen that material costs exhibit the following characteristics:

i. It displays a degree of instability; and

ii. is sensitive to changes in mix proportions.

What are the implications of these observations to practice? For example, if the difference in cost is marginal, then a consultant may continue to specify smaller standard size joint of 10 mm although much larger joints are adopted in practice (Abeysekera, 1996a). On the other hand, as it is not cost significant, sizes may not be specified at all in walls which are either lightly loaded or non-load bearing. However, take the case of walls with 1:5 mixes where the difference is significant. Now, if this was known to a contractor, surely, a 20% difference would have compelled the use of small sizes.

With different sizes of bricks, different sizes of joints with different degrees of joint fullness, different wall widths, and now different mix proportions, how could decisions be made as to what constitute optimality or economy? And if optimality can be achieved would the situation be sufficiently compelling to move towards it? Should the practice of specifying standard joint sizes prevail? Is it necessary? What is the impact of chappari? These are some questions that need to be answered. In order to do so, it is necessary to delve deeper in the search of 'intrinsic' cost features, and to seek answers to the 'why' of the 'instability' and 'sensitivity to mortar mixes' discussed herein.

4.0 Decision Rules for Cost Manipulation

4.1 Cost Densities

'Cost Density' is defined herein as the 'cost of a unit volume' of a material or of a product made out of materials. It may refer to bricks, cement, sand, mortar or brickwork. As would be seen later, this measure was particularly useful in searching for 'intrinsic' reasons for the 'instability' and 'sensitivity' of brickwork costs.

Cost of brickwork is made up of the cost of bricks, cement and sand. As such, a study of the movement of the cost densities of these materials over time was first made. Having failed to find any specific reasons for the 'instability and sensitivity' of brickwork costs, it was decided to examine the cost densities of bricks and mortar and then to compare one against the other. In doing so, it was necessary to make a distinction between the 'mixed state' and the 'in-place' volume of mortar, as the latter was in a denser state than the 'mixed state' mortar.

Accordingly, what needs to be compared with the cost density of bricks is the cost density of 'in-place' mortar and not 'mixed-state' mortar. The former would depend on joint sizes, the degree of joint fullness, the type of sand used, the wall thickness and the brick

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Fig. 2: Material cost indicators of walls with different joint sizes compared with costs of walls with standard joint sizes
size. However, as an approximate estimate, the following procedure was adopted to calculate the volume of 'in-place' mortar.

It can be shown that the proportion of bed mortar (compared with the total volume of mortar) could vary from about 65% to 90% depending on the size of the brick used (Abeysekera, 1996b). Consider the lower bound of 65%, where (say) 0.65 cubic metre of mortar is in the bed joint and 0.35 cubic metre of mortar is in other joints. Then the 'mixed-state' volume of mortar was computed (as before) using the RUM method for medium sand. Accordingly, the 'mixed-state' volume could be shown to be equal to 1.1012 times the 'in-place' volume. This means that the 'mixed-state' volume could be computed by multiplying with a factor of approximately 1.1; for the upper bound of 90%, the factor was 1.14, and is only marginally different. As such, this factor (hereinafter referred to as the 'compound factor for in-place mortar') was taken as 1.12. The cost of 'mixed-state' volume was then computed as shown in section 3.2.2.

Whilst, the above procedure refers to the process adopted for computing the cost density of mortar, the cost density of bricks was computed by dividing the effective price by its size. For this purpose, it was necessary to establish the average size of bricks in different years, which are as given in Appendix 2. The plots of the cost densities of bricks and mortar are shown in Fig. 3.

### 4.2 Deriving Decision Rules

The following observations can be made from Fig. 3:

i. There has been a rapid rise in the cost density of bricks from about 1992.

ii. The cost density of bricks rises steadily cutting across mortar graphs, in somewhat of a cyclic nature. (Compare brick graph with 1:5 and 1:6 mortar graphs.)

The reason for rapid rise in (i) above was due to the rapid rise in the cost of bricks (as explained in section 2.1) and also due to the decline in the size of the brick (see Appendix 2). These factors combine together in accelerating the rate of rise in the cost density of bricks.

The second observation explains the intrinsic reasons for the ‘instability’ and ‘sensitivity’ mentioned in section 3.4. For example, it was pointed out that walls with large joints with a mix of 1:5 has always been costlier except in 1994. This scenario is portrayed clearly in Fig. 3 with the cost density of brick dropping below the cost density of 1:5 mortar. Thus, it may be concluded that when the ‘cost density of bricks’ is greater than the ‘cost density of mortar’ it is cheaper to construct walls with large joints.

This conclusion can be translated into a set of decision rules shown in Fig. 4:

![Unit Volume Costs of Mortar and Bricks](image)

**Fig. 3: The variation of cost densities of bricks and mortar (from 1969-1996)**
A measure which is of central importance to this study is 'Cost Polarity'. This is defined as the ratio of the cost density of bricks to that of mortar. A value equal to 1 indicate that there is no cost difference between bricks and mortar and hence no polarity. The larger the variance from 1, the greater is the polarity. The manner in which this measure was used for investigating the dynamics of brickwork costs is explained in the ensuing sections.

It can be shown that a variation in the BMR of 1.0 to 5.0 represents majority of the cases that would be encountered in practice (Abeysekera, 1996b). As such, the procedure adopted was to compare the cost of walls with BMR ratios of 1.2 and 3 with the base ratio cost of 5.0; the latter being similar to values of 'standard' walls. This procedure was repeated for different values of cost polarities and the results are given in Table 1. The following equations were used for these computations:

\[
\text{Total cost of material (TC) = Volume of bricks (Vb) x cost density of bricks (CDb) + Volume of 'in-place' mortar (Vm) x cost density of 'in-place' mortar (CDm)}
\]

Therefore, \(\% \text{ increase} = \frac{1 - [(Vb2xCP + Vm2) / (Vb1xCP + Vm1)]}{100}\)

where,

CP (i.e. cost polarity) = \(\frac{\text{CDb}}{\text{CDm}}\);

BMR = Bricks to mortar ratio for the \(i^{th}\) set of values;

\(Vb\) = BMR/(1+BMR); and

\(Vm\) = \(1/(1+BMR)\)

4.3 The Cost Polarity of Bricks and Mortar: The Universality

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Note: For cost polarities <1, See Appendix 9.11

Table 1

Percentage reduction in material costs when compared with a bricks/mortar ratio of 5.0 with different cost polarities (>1) of bricks and mortar

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Table 1 shows that a polarity of around 1.2 leads to cost savings greater than 5% in material costs by changing the BMR ratio from 5.0 to 1.0. Furthermore, Fig. 5 shows that as the polarity increases, reductions increase too (i.e. curvilinearly) with a marginal drop in its rate as it increases. Similarly, when the cost polarity is less than 1 (i.e. when cost density of brick is less than mortar), it can be shown that a polarity of around 0.85 is sufficient to bring savings greater than 5% as shown in Fig. 6. These observations lead to the identification of three principal rules for cost optimisation/manipulation; these are presented in Fig. 7. Their ‘universality’ emerge from the fact that these decisions rules are valid irrespective of whether its applied in Sri Lanka or in any other country (global validity), and whether it is applied today or in the future (perpetual validity).

Fig. 5: Cost reductions in material costs with cost polarity > 1

Fig. 6: Cost reduction in material cost with cost polarity < 1
RULE 4
If the Cost Polarity is outside the range 0.85 - 1.20, savings > 5% can be achieved by manipulating the BMR from 1.0 to 5.0 or vice versa, as appropriate.

RULE 5
If, however, the Cost Polarity is within this range, a change in BMR has INSIGNIFICANT impact on costs.

RULE 6
If the Cost Polarity is outside the range 0.75 - 1.40, savings greater than 5% can be achieved by manipulating the BMR from 5.0 to 2.0 or from 2.0 to 5.0, appropriately.

Fig. 7: Decision Rules 4 - 6 for cost optimisation/manipulation;

The ‘Universality’
Note that one of the easiest ways of manipulating BMR is by changing the size of joints.

4.4 The Variation of Cost Polarity Over Time

The thick horizontal lines in Fig. 8 represent polarities of 0.85 and 1.2. The situations which do not fall within this range refer to walls where the BMR could have been manipulated to achieve a cost saving of not less than 5%. A lack of knowledge of such situations would amount to lost cost opportunities.

Examination of polarities related to 1:8-12 mixes for 1996 show that there is opportunity to reduce costs by using larger joint sizes. However, when the mix is 1:5, there is no advantage of using either large or small joints.

The importance of correct proportioning of mortar with respect to cost reduction strategies is clearly shown in Table 1. However, there may also be situations where correct proportioning is of marginal importance for cost reduction, especially when the cost polarities of mixes fall within 0.85 and 1.2.

4.5 Demonstrating the Use of Decision Rules

Three cases are presented herein to illustrate the dynamics of the situation at hand.

Case 1 details:
A contractor built multi-storey office building in the heart of Kurunegala utilised large size bricks. The specified mix and the wall widths were, 1:5 cement-sand and 225 mm, respectively. The contractor purchased cement from hardware shops in the town; although three brands were available, viz. Mitsui, Sansth and a Chinese brand at Rs. 305/-, Rs. 325/- and Rs. 330/- per 50 kg bag respectively, only Sansth was allowed by the Engineer. Sand and bricks were delivered to site by contractors’ suppliers (1996).

Case 2:
A private client was building his own house in Colombo with labour only sub-contractors with a rate of Rs. 800/- per square. All materials were purchased from a reputed hardware shop. Brick sizes varied, with an average of 187 x 94 x 48 mm. The walls were approximately 218 mm. The mix used was 1:8. Bulking at delivery was found to be 10% (1996).
Case 3:

This case involves the construction of a five-star luxury hotel for a holiday resort in the North Central Province. Although bricks were manufactured in this area, local sources could not meet the daily demand of around 5,000 bricks. As such, bricks were transported from Kochchikade at a transport cost of Rs. 1/- per brick (including unloading). A load of bricks, which was approximately 199 x 98 x 55 was Rs. 1,650/- at the kiln (including loading charges). Sand was purchased from local sources. Cement was transported from Colombo with a delivered price of around Rs. 225/- per bag. Specified mix was 1:8 with a wall width of 225 mm. Labour only sub-contractors were engaged at a rate of Rs. 700/- per square. (1994).

Data

<table>
<thead>
<tr>
<th>Brick sizes, mixes and wall widths</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case 1</strong></td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Brick sizes in cases 1 & 2 refer to 'unit averages'.

Dry factors: Type of sand: Medium; Dry factor = 1.061

Basic prices of materials delivered to site (in Rs.)

<table>
<thead>
<tr>
<th></th>
<th>Bricks /1000</th>
<th>Cement/50 kg bag</th>
<th>Sand/Cube</th>
<th>Bulking at delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>1,400/-</td>
<td>330/-</td>
<td>666.67</td>
<td>0.20</td>
</tr>
<tr>
<td>Case 2</td>
<td>1,500/-</td>
<td>300/-</td>
<td>1,000.00</td>
<td>0.18</td>
</tr>
<tr>
<td>Case 3</td>
<td>2,650/-</td>
<td>250/-</td>
<td>500.00</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Wastage factors:

<table>
<thead>
<tr>
<th></th>
<th>Bricks</th>
<th>Sand</th>
<th>Cement</th>
<th>Mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>7.5%</td>
<td>5%</td>
<td>0%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Case 2</td>
<td>7.5%</td>
<td>5%</td>
<td>0%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Case 3</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

Joint scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>BMT (mm)</th>
<th>TH (mm)</th>
<th>TS (mm)</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>1(1.1577)</td>
<td>1</td>
<td>0.85</td>
<td>0.85</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>17.11</td>
<td>20.87</td>
<td>14.67</td>
<td>1(1.1577)</td>
<td>1</td>
<td>0.85</td>
<td>0.85</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>25.4</td>
<td>37.43</td>
<td>25.41</td>
<td>1(1.1577)</td>
<td>1</td>
<td>0.85</td>
<td>0.85</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Results for decision making

Cost densities & polarities

<table>
<thead>
<tr>
<th></th>
<th>Cost Density</th>
<th>Mortar Cost</th>
<th>Cost Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bricks</td>
<td>Mortar</td>
<td>Polarity CP</td>
</tr>
<tr>
<td>Case 1</td>
<td>1,281.30</td>
<td>2,586.70</td>
<td>0.50</td>
</tr>
<tr>
<td>Case 2</td>
<td>1,908.70</td>
<td>1,789.25</td>
<td>1.07</td>
</tr>
<tr>
<td>Case 3</td>
<td>2,745.12</td>
<td>1,289.16</td>
<td>2.13</td>
</tr>
</tbody>
</table>

Decision criterion: Cost polarity between 0.85 and 1.2, no potential for significant savings.

CP < 0.85: Much opportunity. Use small joints.

0.85 < CP < 1.2: Not possible.

CP > 1.2: Much opportunity. Use large joints.

(C) Verifying Results

Cost densities of brickwork (Rs. per cu.m.)

<table>
<thead>
<tr>
<th>Joint</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>% Reduction</th>
<th>Remarks on reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>1,630.26</td>
<td>1,764.97</td>
<td>1,908.41</td>
<td>17.1%</td>
<td>Significant. Reduce joint sizes.</td>
</tr>
<tr>
<td>Case 2</td>
<td>1,850.67</td>
<td>1,846.10</td>
<td>1,869.21</td>
<td>-</td>
<td>No change.</td>
</tr>
<tr>
<td>Case 3</td>
<td>2,284.41</td>
<td>2,148.08</td>
<td>2,044.01</td>
<td>10.5%</td>
<td>Significant. Increase joint sizes.</td>
</tr>
</tbody>
</table>

i. Volumes of mortar calculated by using the RUM method.

ii. Also see Fig. 4: Decision Rules 1-3 and Fig. 7: Decision Rule 4-6.

The decision criteria adopted in the above section is justified by the results seen herein.

These cases, therefore, illustrate that there is opportunity for reducing costs by seeking a 'dynamic approach' to joint sizes rather than a 'static' approach of prescribing a standard size; The Decision Rules are thus of practical value in this respect and may easily be used for making decisions at the time of purchasing materials and/or at the time of use.

5.0 Coping with Chaos

5.1 Brickwork Joints

The thrust of the manipulation in the preceding section was between the volume of mortar and the volume of bricks based on their cost polarity. The volume of mortar in brickwork could be manipulated by changing joint sizes; Of all the joints, the bed joint takes centre place for two reasons; firstly, it contains the largest proportion of mortar in all joints (Abeysekera, 1996b); and secondly, it's size can be changed independent of the size of the brick. In view of the first comment, it may be said that the 'chapparu' which characterise Sri Lankan brickwork is of any significance due to the low proportion of mortar in brickwork joints (Abeysekera, 1996b). Clearly, the claim that 'chapparu, leads to a waste of expenditure' does not hold true always; in fact, it may be used to advantage when the cost polarity is greater than 1.2, for reducing brickwork costs.

The cost effectiveness advocated herein is essentially 'dynamic' in nature; It is borne out of chaos, as a strategy for coping with it, by harnessing it's advantages. Given the emerging nature of the future which is largely unpredictable, this strategy is only logical; The 'Decision Rules' developed in this study have made the 'complexity' of the situations, a relatively easy task to cope.

5.2 Bricks

The lack of an easy and effective methodology to assess the impact of the chaos on costs has resulted in what may be referred to as the 'economic chaos' of brickwork. The question on the selection of a cost-effective brick size is discussed in this section.

Volume of mortar in brickwork (and hence the BMR) can be regulated not only by changing the size of the bed joint but also by using different sizes of bricks. For
example, a smaller brick would result in a greater proportion of mortar than when using a larger brick. As such the ‘Decision Rules’ illustrated in section 4.2 and demonstrated in section 4.5 could also be used in the selection of an appropriate brick.

**Case 1: Cost Polarity between 0.85 and 1.2**

Select brick with the lowest cost density in order to reduce material costs; cost densities being same larger/taller bricks may be selected for increasing hourly output.

**Case 3: Cost Polarity > 1.2**

In sub-case 1, select the small brick.
In sub-case 3, select the small brick.

In sub-case 2, select the brick with the lowest cost density; build with the ‘largest’ buildable bed joint (Abeysekera, 1997); the actual choice of the brick could be made by using one of three methods given under Case 2: sub-case 3.

**WHICH SIZE?**

<table>
<thead>
<tr>
<th>Sub-case 1: Cost densities of bricks equal:</th>
<th>Sub-case 2: Cost density of large brick less:</th>
<th>Sub-case 3: Cost density of large brick greater:</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Small](CD = 10)</td>
<td>![Large](CD = 8)</td>
<td>![Large](CD = 15)</td>
</tr>
</tbody>
</table>

Fig. 9: Cost density scenarios for brick selection

**Case 2: Cost Polarity < 0.85**

Three sub-cases need to be considered as shown in Fig. 9 (for the purpose of applying the decision rules). In sub-case 1, select large brick.
In sub-case 2, select large brick.
In sub-case 3, build with the smallest buildable bed joint (Abeysekera, 1997); the actual choice of the brick could be made by using one of three methods given below:

**Method 1:**
Select large brick (over the small brick) if
volume difference > Price difference/CD of mortar.

**Method 2:**
Select large brick, if (2(CP2 - 1) + (1/2) (CP2 - CP1) + (1(1 - CP1) < 0
where
(1, 2 are the BMK’s for bricks 1 and 2, whereas CP1 and CP2 are the cost polarities for bricks 1 and 2.

**Method 3:**
Calculate the total cost (as given in 3.2.1) and select the cheapest.
(Note: Method 1 is an approximate method.)

In the event, it is necessary to compute the price that can be paid, say to a standard size brick, the procedure given in Method 3 or as illustrated by Kodikara (1996), and Abeysekera (1996c) may be used.

**5.3 Estimating Brickwork Costs**

The conventional method adopted by industry for estimating the cost of brickwork is to use ‘standard norms’ (Abeysekera, 1996a). These norms fail to take account of variations in brick sizes and joint sizes adequately. Consequently, the estimates are inaccurate. The current chaos therefore demands a change in the method of estimating; standard norms have no place in an environment where there are no ‘standards’. The strategy therefore, should be to have a dynamic approach to estimating based on the methodology given in section 3.2.1. This procedure can be simplified further when the cost polarity lies in the range 0.85-1.2; multiplying the volume of the wall by the cost density of either the bricks or mortar or preferably by the average of the two, would give the cost of brickwork.
The Decision Rules given in this study could be applied for arriving at a 'least cost' estimate as well by adopting appropriate brick and joint sizes, which would in turn increase competitiveness, especially in projects where brickwork costs are significant.

5.4 The Cost Homogeneity

The discussions in Section 4.3 established an important decision rule for dealing with chaos. It was shown that as long as cost polarity is within 0.85 and 1.2, significant savings in costs cannot be achieved by changing variables such as the brick size, the bed joint size, the cross joint sizes, and chappar. This feature is defined herein as the 'cost homogeneity' of brickwork. The implication to practice is that when there is cost homogeneity there is hardly any need to control the bricks to mortar ratio from the point of view of costs.

5.5 Issues related to Strength

This study concentrated on non-load bearing (as in reinforced concrete structures where walls are used as in-fill panels) and lightly loaded walls (as in single storey or two storey houses). Thus, strength is not a significant issue. For example, Kodikara (1996) has shown that current Kochchikade bricks could safely be used as a load bearing wall in two storey buildings. Unfortunately, the main drawback of this study has been its inability to qualify this conclusion with respect to the strength of bricks. However, walls built with mud do stand for centuries, so why not walls with burnt clay bricks and cement mortar? (de Vos, 1977)

However, when implementing approaches advocated in this study, one may rightly argue that such non-structural applications may have to draw upon the knowledge base of structural theory especially if large openings are present or if concentrated loads are applied. As such, it may be necessary to take suitable precautions.

5.6 Further Research

This study focused on one brick thick walls and strategies recommended for these walls could even be applied to half brick thick walls. However, it would be useful to undertake further research to ascertain, for example, the impact of larger bed joint sizes on increased creep and shrinkage, ability to carry stresses in shear and flexure (due to wind loads or due to accidental loads), and ability to resist differential settlement and the like, although there does not appear to be industry signals suggesting such initiatives.

6.0 Conclusions

Many factors affect costs which change with time. The future, especially the long term future, is unpredictable. Furthermore, the situation vary from site to site, within sites and from region to region too. As such, it was argued that static solutions cannot lead to cost effectiveness. The examination of the past confirmed this.

'Instability' and 'sensitivity to mortar mixtures' were characteristics exhibited by material costs. Analyses with 'cost densities' of bricks and mortar led to the identification of 'intrinsic' reasons for these characteristics; These in turn led to the development of a set of 'decision rules' for coping with chaos.

The initial decision rules were based on whether the cost density of bricks was greater than or less than mortar. For example, it was shown that when the cost density of bricks were higher, it would be economical to use more mortar for constructing walls. However, these decision rules failed to indicate whether there would be significant cost savings by moving towards the scenarios indicated by them.

Subsequent development of three 'Decision Rules' for cost optimisation/ manipulation based on the values of 'cost polarity' (i.e. Decision Rules 4, 5 and 6) overcame this deficiency by quantifying the reductions with respect to cost polarity. These decisions rules established the 'universality' in brickwork costs. Two ranges of cost polarity, based on a cost reduction of not less than 5% were identified with respect to two changes in the bricks to mortar ratio (BMR), i.e. from 5.0 to 2.0, and from 5.0 to 1.0; It was shown that such changes could be brought about by adjusting the sizes of joints (especially the bed joint) and/or by selecting appropriate sizes of bricks. These paved the way for overcoming the 'economic chaos' of brickwork.

The Decision Rules are a major breakthrough in coping with the economic aspects related to brickwork costs and are suitable for use in situations where labour sub-contractors are employed and/or in situations where labour cost is marginal; They relate to 'intrinsic' cost features of brickwork and are 'universal' (global validity) and 'time independent' (perpetual validity). They lead to 'dynamic' solutions for minimising costs, as for example by appropriate changes to the bed joint size. Such changes call for 'flexibility' on the part of industry. Their application to 'industry situations' were demonstrated; and their validity established.
'Cost homogeneity' in brickwork is a feature embodied in these Decision Rules, despite the heterogeneity of material prices; Cost homogeneity means that variations in brick size, the bed joint size, the cross joints, chapparu do not have a significant impact on costs within a certain range of values of polarity given earlier; The implication to practice is that, as long as the situation at hand is such, then there is hardly any need to control the bricks to mortar ratio (for example, brick or joint sizes) from a cost perspective.

The environment in which decisions have to be made is 'complex'; Complex because of the unpredictability of the future; the chaos in the study variables; the diversity of the factors which affect choices; and the goals of many who make these choices. Industry cannot escape from this reality and have to learn to cope with such complexity. The simplicity of the 'Decision Rules' is a major breakthrough and provides an implementable approach to coping with this 'complex chaos' in brickwork.

7.0 References


Abbreviations:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF</td>
<td>Bulking factor</td>
</tr>
<tr>
<td>BMR</td>
<td>Bricks to mortar ratio</td>
</tr>
<tr>
<td>BMT</td>
<td>Bed mortar thickness</td>
</tr>
<tr>
<td>BSR</td>
<td>Building Schedule of Rates</td>
</tr>
<tr>
<td>CD</td>
<td>Cost density</td>
</tr>
<tr>
<td>CP</td>
<td>Cost polarity</td>
</tr>
<tr>
<td>ICTAD</td>
<td>Institute for Construction Training and Development</td>
</tr>
<tr>
<td>MLGH&amp;C</td>
<td>Ministry of Local Government Housing and Construction</td>
</tr>
<tr>
<td>NSS</td>
<td>National Sand Study of Sri Lanka</td>
</tr>
<tr>
<td>OPC</td>
<td>Ordinary Portland Cement</td>
</tr>
<tr>
<td>PHSWT</td>
<td>Plantation Housing and Social Welfare Trust</td>
</tr>
<tr>
<td>RUM</td>
<td>‘Representative Unit Method’ of computing mortar volumes</td>
</tr>
<tr>
<td>S/c</td>
<td>Sub contract</td>
</tr>
<tr>
<td>SEC</td>
<td>State Engineering Corporation</td>
</tr>
<tr>
<td>TH</td>
<td>Thickness of cross joint in header course (in single brick thick walls)</td>
</tr>
<tr>
<td>TS</td>
<td>Thickness of cross joint in stretcher course</td>
</tr>
<tr>
<td>TW</td>
<td>Wall width</td>
</tr>
</tbody>
</table>

Appendix 1: A broad classification of bricks available for use in and around Colombo

Group 1: Extra-large (from Embilipitiya) - 240 x 140 x 93 - Rarely available.

Group 2: Standard size (SEC brick and special suppliers): 232x105x61; 216 x 105 x 67 - Difficult to obtain.

Group 3: Large size (from Kaduwela, Hanwella, Kotadeniyawa) - 203 x 102 x 2; 193 x 92 x 56 - Not as freely available as Group 4 bricks.

Group 4: Small size (from Kochchikade and nearby areas) - 175x91x51; 165 x 87.5 x 48 - Widely available

Note: Sizes given herein are for broadly identifying the different sizes; Sizes are given in millimetres.
Appendix 2: Brick sizes assumed for computation of unit volume cost of bricks

<table>
<thead>
<tr>
<th>Year</th>
<th>Length</th>
<th>Breadth</th>
<th>Height</th>
<th>Source/Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>206.4</td>
<td>101.6</td>
<td>57.2</td>
<td>Based on examination of sizes used in a building constructed in 1972; Imperial size: 8 1/8” x 4’x 2 1/4”</td>
</tr>
<tr>
<td>1979</td>
<td>203.2</td>
<td>98.4</td>
<td>54</td>
<td>Assumed as 8i x 3 7/8” x 2 1/8” in keeping with the general decline in size.</td>
</tr>
<tr>
<td>1981</td>
<td>203.2</td>
<td>98.4</td>
<td>54</td>
<td>Taken to be same as above.</td>
</tr>
<tr>
<td>1985</td>
<td>198</td>
<td>96</td>
<td>49</td>
<td>Same as 1986 data given below.</td>
</tr>
<tr>
<td>1986</td>
<td>198</td>
<td>96</td>
<td>49</td>
<td>Abeysekera, 1987; Site Survey data</td>
</tr>
<tr>
<td>1988</td>
<td>193.50</td>
<td>94.50</td>
<td>48.0</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>191.25</td>
<td>93.75</td>
<td>47.5</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>189</td>
<td>93</td>
<td>47</td>
<td>Abeysekera, 1990; Site survey data</td>
</tr>
<tr>
<td>1991</td>
<td>189</td>
<td>93</td>
<td>47</td>
<td>1990 values when compared with data for mortar consumption wall appear to be similar.</td>
</tr>
<tr>
<td>1992</td>
<td>189</td>
<td>93</td>
<td>47</td>
<td>Established based on interviews with brick transporters. Taken as 1996 values. See Chapter 3.2.7</td>
</tr>
<tr>
<td>1993</td>
<td>177</td>
<td>90</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>177</td>
<td>90</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>177</td>
<td>90</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>177</td>
<td>90</td>
<td>47</td>
<td>Site survey, 1996</td>
</tr>
</tbody>
</table>

Note: Years given tally with price data in Appendix 3

Appendix 3: Data for Material Prices (in Rs.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Kochchukade bricks per 1000</th>
<th>Cement per 50 kg bag</th>
<th>Sand per cube</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>90.00</td>
<td>11.25</td>
<td>30.00</td>
<td>Statistical Bulletin, MLGH&amp;C</td>
</tr>
<tr>
<td>1979</td>
<td>200.00</td>
<td>45.00</td>
<td>119.34</td>
<td>Statistical Bulletin, MLGH&amp;C</td>
</tr>
<tr>
<td>1981</td>
<td>344.17</td>
<td>89.50</td>
<td>167.00</td>
<td>Archives of a private house builder</td>
</tr>
<tr>
<td>1985</td>
<td>486.28</td>
<td>113.02</td>
<td>281.83</td>
<td>Statistical Bulletin, MLGH&amp;C</td>
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<tr>
<td>1986</td>
<td>500.33</td>
<td>110.60</td>
<td>296.58</td>
<td>Statistical Bulletin, MLGH&amp;C</td>
</tr>
<tr>
<td>1987</td>
<td>532.93</td>
<td>116.19</td>
<td>336.71</td>
<td>ICTAD Database</td>
</tr>
<tr>
<td>1988</td>
<td>662.54</td>
<td>116.72</td>
<td>393.74</td>
<td>- Do -</td>
</tr>
<tr>
<td>1989</td>
<td>749.23</td>
<td>132.84</td>
<td>428.05</td>
<td>- Do -</td>
</tr>
<tr>
<td>1990</td>
<td>813.58</td>
<td>175.25</td>
<td>484.48</td>
<td>- Do -</td>
</tr>
<tr>
<td>1991</td>
<td>844.23</td>
<td>172.80</td>
<td>563.67</td>
<td>- Do -</td>
</tr>
<tr>
<td>1992</td>
<td>939.78</td>
<td>192.17</td>
<td>654.63</td>
<td>- Do -</td>
</tr>
<tr>
<td>1993</td>
<td>1,233.95</td>
<td>213.90</td>
<td>719.27</td>
<td>- Do -</td>
</tr>
<tr>
<td>1994</td>
<td>1,598.27</td>
<td>237.11</td>
<td>890.69</td>
<td>- Do -</td>
</tr>
<tr>
<td>1995</td>
<td>1,457.78</td>
<td>242.46</td>
<td>1,089.26</td>
<td>- Do -</td>
</tr>
<tr>
<td>1996</td>
<td>1,434.51</td>
<td>268.77</td>
<td>1,088.02</td>
<td>- Do -</td>
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