Unedited/Not for Publication

VOLUME ONE

Text and References

FINAL REPORT

LATERITIC MATERIALS IN RURAL HOUSING CONSTRUCTION IN GHANA

LATERITE HOUSING GHANA PROJECT -3-P-88-0152

An Engineering Study Funded by the
INTERNATIONAL DEVELOPMENT RESEARCH CENTRE (IDRC)
Ottawa, Canada

BUILDING & ROAD RESEARCH INSTITUTE
(Council for Scientific & Industrial Research)
University P.O. Box 40, Kumasi, Ghana

FINAL REPORT

LATERITIC MATERIALS IN RURAL HOUSING CONSTRUCTION IN GHANA

Mensah David Gidigasu
(Project Leader/Snr. Researcher)

BUILDING & ROAD RESEARCH INSTITUTE (CSIR), KUMASI
INTERNATIONAL DEVELOPMENT RESEARCH CENTRE (IDRC), OTTAWA, CANADA

SEPTEMBER, 1993

THE PROJECT PROFILE

Project Title: LATERITE HOUSING IN GHANA: Centre File: 3-P-88-0152

Duration of Project: 3 years (4/7/1989 - 4/7/1992)

Funding Agency: International Development Research Centre (IDRC), P. O. Box 8500, Ottawa, Canada, KIG 3H9

LOCATION OF PROJECT

Building and Road Research Institute (BRRI), Council for Scientific and Industrial Research (CSIR), University P.O. Box 40, Kumasi, Ghana.

KEY PROFESSIONAL PROJECT STAFF

Dr. Mensa David Gidigasu, Project Leader and Senior Researcher

Mr. James C. Ahiale, Architect, Researcher

Major (Rtd) Emmanuel A. Solomon (later Mr. E.Osei-Tutu), Building Technologist, Researcher

TECHNICAL BRRI SUPPORTING STAFF

Mr. Emmanuel Appeagyei, Chief Technician, Building Construction

Mr. Emmanuel Mate-Korley, Chief Technician, Soil Technology

Mr. Ernest Dougan, Principal Technician, Soil Technology

Mr. C.A. Wilson, Senior Technician, Soil Technology

Mr. A. Adjei-Duffour, Technician, Soil Technology

PROFESSIONAL CONSULTANTS TO THE PROJECT

Dr. John K. Ocloo, Non-exportable timber technologist and Termite Control Specialist, Researcher (BRRI)

Mr. Rexford Asiama, Researcher, Soil Pedologist (SRI)

Mr. Mike Owusu-Siaw, Graphic and Illustrations Design Specialist, Researcher (BRRI)

Mr. D.O.K. Kuma, Engineering Geologist (BRRI)

Mr. P.T. Ankrah, Geologist, Ghana Geological Survey Department

Mr. Ampem K. Darko, Accountant

MEMBERSHIP OF NATIONAL CONSULTATIVE COMMITTEE

1. Mr. S.Y. Bortsi, Ministry of Industries, Science and Technology, P. O. Box M.39, Accra.
2. Mr. Y.A. Agyeisaw/ Mr. M. Berko, Ministry of Works and Housing, P.O. Box M.43, Accra.
3. Mr. S.Y. Effah/Mr. M.M. Lansah (DRHCI), Ministry of Local Government, P.O. Box M.50, Accra.
4. Mr. M.O. France, Ministry of Health, P.O. Box M.44, Accra.
5. Ministry of Education, P.O. Box M.45, Accra (Nobody nominated to attend).

FOREIGN PROJECT RESOURCE PERSONS

1. Mr. Fodio KOIDA AD ADAUA
   BP 3898
   Ouagadougou
   Burkina Fasso

2. Mr. Faustin VLAMI-BI-DOU
   Director, LETP
   04 BP3, Abidjan 04
   Cote d'Ivoire

3. Dr. Mamadi TOURE
   Dept. de Genie Civil
   Universite de Conakry
   BP 1147
   Conakry, Guinee

4. Dr. Meiga M.S.
   Ecole des Mines et de la Geologie
   BP 732
   Niamey
   Republic of Niger

5. Prof. Kunle Ade WAHAB
   Obafemi Awolowo University
   Faculty of Engineering, Design and Management
   P. O. Box 1075
   Ile-Ife
   Nigeria

6. Mr. Malick GAYE
   Enda T.M.
   Equipe r.u.p.
   rue Carrot Nousso Diop
   BP 3370
   Dakar, Senegal

7. Mr. Foli EPHOEVI-GA
   Centre de la Construction et de Logement
   BP 1762
   Lome
   Republic of Togo

8. Mr. M.V. KAMGUEU
   Ecole Polytechnique
   Dept. de Genie Civil
   BP 728
   Yaounde, Cameroon

KEY WORDS/PHRASES

Homelessness; developing countries; earth buildings; construction technologies; performance of earth buildings; environment and climatic factors; lateritic materials; lateritic rural houses; Atakpame; wattle and daub; rammed earth; lateritic stone walling technologies; small-scale production of lateritic walling components; lateritic-soil-lime adobe blocks; improved design; lateritic houses; self-help housing construction; demonstration buildings construction; protection of lateritic walls; technology transfer processes; affordable rural houses; geotechnical characterisation; criteria for selecting walling lateritic materials; manufacture of lateritic stone block cutter; community participation project execution; training of rural housing artisans; rural housing societies; simple earth building construction manuals; TEK Block Press; rural settlement planning; building materials specifications; Rural housing strategies, standards and codes of practices.

C O N T E N T S

ACKNOWLEDGEMENTS

The opportunity to execute this project would not have been possible without the generous funding by the International Development Research Centre (IDRC), Canada. The key personalities that the project leader and senior researcher had the benefit of working closely with include Dr. Mousseau Tremblay, Director, Earth and Engineering Sciences Division of IDRC, Dr. Aung Gyi, then Associate Director, Earth and Engineering Sciences Division, Co-operative Programmes, who organised the post-CIB congress in Washington D.C., for participants from seventeen developing countries, followed a year later by a Project Identification Meeting organised by the IDRC and the Commonwealth Science Council (CSC) in Nairobi, December, 1987. His interest and encouragement to the project leader highly stimulated the execution of the project. Dr. Rachel Des Rosiers, Deputy Director, Earth and Engineering Sciences Division (IDRC) contributed greatly to the success of the project through his positive interventions at some critical stages of the project execution. We acknowledge the immense contribution made during the administration of the project by the then Regional Director, Dr. Pierre Sane; the Regional Programme Officer for Earth and Engineering Sciences Division, Mr. Serge Dube, who was at the final stage of the project succeeded by Dr. Michael Bassey, Principal Programme Officer, Environment and Natural Resources Division. The project team is also grateful to the Regional Controllers, Messrs. Claude Benard and Jean-Paul Joly, for their co-operation throughout the period of the project execution.

Our thanks also go to Dr. Valerie Monkhouse, Associate Director, Information Sciences Division, IDRC, Ottawa, Canada, and Mr. Allione B. Camara, Regional Programs Officer for West and Central African Office in Dakar, Senegal, for their great assistance in providing the project team with very valuable information on earth building technologies from various parts of the world.

In Ghana, we are grateful to the Minister of Science and Technology, Canadian High Commissioner, as well as the Director-General of C.S.I.R., for their support and encouragement during the project execution.

The project was executed within the framework of the co-operative agreement signed between IDRC (Government of Canada) on the one hand and the C.S.I.R. (Ghana Government) on the other on the 8th January, 1988.

The moral and scientific inputs by the Resource persons from the various institutions in the West and Central African countries are gratefully acknowledged.

Last but not the least, the project team gratefully acknowledges the assistance given by the staff of the Building and Road Research Institute (BRRI) (CSIR) without which the successful completion of the project might not have been possible.

PREFACE

The world population explosion within the last few decades has created very serious housing problems especially in developing countries. In the era of imported portland cement, lime, and other cementitious materials the traditional practices of housing construction have undergone serious decline in many developing countries.

While some countries are still able to import sufficient foreign construction materials to meet their national housing needs, there are other depressed countries which are unable to do so due to scarce foreign currency resources.

United Nation Agencies and other international donor organisations have attempted in recent years to address the problem of inadequate housing delivery in developing countries.

The emphasis in these attempts has been focused on the use of local materials and upgrading of traditional construction technologies through local materials identification, characterisation as well as training of construction artisans.

Introduction of innovative designs taking into consideration the climatic environments has also become an area of special studies.

The current project funded by the International Development Research Centre (IDRC) is a contribution to this global effort aimed particularly at upgrading lateritic housing construction technologies for the rural poor. Indeed, many similar studies have been undertaken in other parts of Africa, Middle East, Asia and Latin America, to revive and upgrade earth building construction strategies.

Following the 10th biennial Congress of the CIB in Washington D.C., in 1986, the International Development Research Centre (IDRC) organised a post-congress workshop for participants from 17 developing countries, namely: China, India, Ethiopia, Bangladesh, Sudan, Peru, Pakistan, Turkey, Egypt, Brazil, West Indies, Nigeria, Guatemala, Mexico, Phillipines and Ghana. Participants from 14 countries including Ghana participated at the post-congress workshop at which many housing delivery problems and strategies for developing countries were discussed. The possibility of participants presenting project proposals for possible IDRC funding were also discussed. At a follow-up Projects Identification Meeting held in Nairobi (Kenya) in December, 1987, sponsored jointly by the IDRC and the Commonwealth Science Council (CSC), project proposals in three earthen housing construction materials areas, namely: natural stone, brick and tile and raw earth were discussed and evaluated at the meeting.

The project proposal on the potential use of lateritic materials for housing construction in rural Ghana was accepted by IDRC for funding. It was a three-year duration project and its execution was undertaken by a team comprising an architect, laterite soil engineer, a building construction technologist, as well as land surveyor, soil and construction technicians. Specialist on the use of secondary species of timber for construction, an engineering geologist and a soil pedologist assisted at various stages of the project execution.

The Inception and First Technical Report of 242 pages (plus 44 pages of 5 appendices) was submitted to IDRC at the end of the first year; this was followed by the 2nd Technical Report of 354 pages at the end of the second year. The present one which is the third and final technical report, constitutes the summary of conclusions of the three (3) year project execution activities and findings. This report is in 2 volumes; volume 1 (239 pages) contains the text and references; while volume 2 (372 pages) constains tables, figures, and appendices.

The project execution was rounded up with a seminar on "Lateritic Materials in Rural Housing Construction" held from 18-21 May, 1993, in Kumasi, Ghana. The proceedings of the seminar constitutes the crucial document on lateritic housing.

The proceedings of the seminar, is presented as a significant contribution to current documentation on low-cost lateritic housing delivery technologies in West Africa. Indeed, the incorporation of inputs of some foreign expert resource persons in the proceedings makes the document a valuable source of reference information on lateritic rural housing construction in the sub-Saharan Africa.

The project execution was carried out in six phases:

The first phase involved some additional characterisation studies on the dominant Ghanaian lateritic materials necessary to relate to the durability with a view to developing and use of the lateritic materials for building construction. The materials studied included lateritic stones, boulders, pebbles, gravels through fine-grained sandy, silty and clayey materials. The tests carried out on the materials included the standard geotechnical tests for characterising natural and stabilised materials and soils as well as some other non-traditional tests developed specifically for evaluating lateritic materials. Empirical tests traditionally used for assessing soils for earth building construction were also briefly discussed. Physico-chemical and mineralogical studies were also undertaken on selected materials.

The second phase of the study consisted of the assessment of the performance of existing lateritic buildings in the main climatic zones of Ghana defined in terms of the so-called "Moisture Index". Existing lateritic house owners were interviewed about the materials used in the construction of their houses, the age of the buildings, and material samples were taken from the existing walls as well as the old borrow areas where the builders collected the walling materials. The soils from the existing walls and old borrow areas were studied for geotechnical properties in the Institute's laboratory. The differential degrees of desiccation of materials in the existing walls and those freshly dug close to the ground surface posed some problems; this problem was partly solved through careful selection of laboratory testing procedures. Over three hundred (300) samples taken from the existing walls and soil borrow areas in the climatic zones were examined, tested and analysed. The objective here, was to establish some possible relationship between the performance of the existing earth buildings and the properties of the specific materials used in their construction.

The third phase comprised analysis of results of studies in the first two phases with the view to isolating good, borderline, and poor materials for earth walling in untreated form. It also provided the opportunity for improving the characteristics (through mechanical stabilisation with sand) of materials that did not meet some basic specifications, such as particle size distribution and plasticity and shrinkage properties compared with materials that are known to perform satisfactorily in existing Atakphame, wattle and daub, and adobe block buildings in a given climatic and drainage conditions. The main process of improving most of the sub-standard materials was by mechanical stabilisation through addition of missing particles or removing the oversize gravel particles.

One of the important findings pointed to the strong relationship that exists between the composition of the materials and their performance as earth walling materials. For example, it was clear that any attempt to formulate criteria for selecting suitable lateritic materials or modifying the properties of the local materials should take into consideration not only standard geotechnical characteristics, but also such compositional factors as the chemistry, the mineralogy, etc, which depended to a great extent on the degree of lateritisation and desiccation of the materials in profiles in relation to topographic site and drainage conditions.

Existing knowledge on genetic features of local lateritic stones or rocks indicate that two main types (in terms of the main chemical composition) abound in Ghana, namely, the aluminous and the ferruginous lateritic stones, pebbles, pisoliths and gravel sizes.

Various attempts have been made in the past to extract lateritic stones and boulders for walling purposes in Ghana. The lateritic stones and boulders were either shaped by hand into blocks or used as such for walling utilising either clay, soil-lime or sand-cement mortars. The success of the lateritic stone cutting process depended to a great extent on the homogeneity, degrees of cementation, desiccation, degradation and brittleness etc. of the stony material. The best results appeared to have been obtained for the soft highly hydrated lateritic materials which were rather soft at the time of cutting but hardened later on exposure to air drying.

The ease of characterisation of the lateritic soils or the processing of lateritic stone into blocks for walling was also found to depend on the micro and macro structures of the raw materials.

The project execution in this phase also involved the design and manufacture of an equipment for cutting lateritic stones into blocks for walling purposes. The equipment at this stage is capable of cutting boulders already sampled from the field; however, it is expected that the equipment will be modified and put on wheels to enable builders cut shallow sheets of lateritic rocks insitu into blocks. Some crushed lateritic stone aggregates had been found during an earlier study to be useful for producing concrete blocks for walling; some of the results of this earlier studies have also been summarized and presented in this report.

Studies were also undertaken to improve the characteristics of the fine-grained highly plastic lateritic clayey soils through locally produced lime stabilisation. The stabilised materials were especially assessed in terms of their response to the pretest handling effects; namely, mixing time, and moulding conditions on the one hand, and the strength development, durability and weathering resistance on the other.

Raw adobe, lime stabilised soil, and lateritic stone blocks produced were used to construct exposure walls at Fumesua to observe their response to climatic and weather factors before the construction of some demonstration buidlings were started; this caused some delay.

An important aspect of the study was the assessment of the existing design and construction technologies of lateritic houses. Based upon information collected during the earlier stages of the project execution, the project architect and the materials and foundation engineer looked into the problems of appropriate foundation design, walls construction and protection as well as the effect of building designs on the safety of the walls against driving rains, wall protection generally against weathering effects of the climatic factors, and the use of locally developed water-proof plasters for earthen walls.

The improvement of foundation design and construction practices to prevent erosion, and to ensure proper drainage through construction of drains, as well as determination of optimum thickness of walls appropriate to various walling components and construction technologies (rammed earth, adobe, soil-lime blocks, and lateritic stone) were also touched on from available literature and field experience sources.

Design and strengthening of joints, as means of increasing the efficiency of construction by utilising detachable and re-usable formwork for rammed wall construction were also studied from relevant foreign literature sources.

The crucial aspect of the project execution was perhaps the construction of lateritic demonstration residential building as well as two demonstration clinics and resource centres through self-help as major process of technology transfer and training of the rural artisans. Within short periods some unskilled workers were able to mould adobe blocks and erected their own houses, near the demonstration building sites.

The project team noted with satisfaction that the majority of those who provided communal labour in the construction of the demonstration buildings were able to acquire the skills of moulding blocks and erecting earth walls and were able to put up their own one to two bedroom dwelling houses at very short periods.

The project team believes that all that they may need is the community TEK BLOCK MACHINE and they can become nucleus of rural self-help housing delivery articulators..

The final stage of the study related to the evaluation of local and foreign earth building design materials specifications and proper construction practices for delivering affordable and durable earth buildings using tropical earthen materials with particular reference to lateritic materials that occur in West Africa. Such problem areas as economics of lateritic housing delivery, institutionalisation of rural lateritic housing delivery processes and the strategies for developing new building materials were also reviewed from local and foreign literature sources.

THE PRODUCTION OF MANUALS FROM THIS TWO VOLUME REPORT IN SIMPLE LOCAL LANGUAGES FOR USE BY RURAL ARTISANS, RURAL BUILDING SOCIETIES, AND SMALL-SCALE BUILDING CONTRACTORS SHOULD ENSURE THE GREATEST IMPACT OF THIS STUDY ON ENHANCING RURAL LATERITIC HOUSING DELIVERY PROCESS IN THE ECOWAS SUB-REGION.

IT IS ALSO STRONGLY RECOMMENDED THAT IDRC PROPOSES TO THE CANADIAN INTERNATIONAL DEVELOPMENT AGENCY (CIDA) TO SUPPORT THE CONSTRUCTION OF MORE RURAL DEMONSTRATION CLINICS, VOCATIONAL CENTRES, AND SCHOOL BUILDINGS, ETC. IN THE ECOWAS SUB-REGION TO HASTEN THE TRANSFER OF LATERITIC RURAL HOUSING TECHNOLOGY TO IMPROVE THE QUALITY OF RURAL EARTH HOUSING IN THE SUB-REGION.

INTRODUCTION

It is probable that about 40-60% of the world's population live in poor shelter conditions by international standards. This is so because inspite of major efforts by national, regional international institutions including the U.N. agencies to address the problem of inadequate shelter and housing delivery for the poor, inability to provide decent shelter for the poor in developing countries remains one of the most challenging problems facing the world after insufficient food delivery to feed the alarmingly growing world population. A special United Nations Agency has been established to deal with the global problems of shelter and housing delivery and their related problems. Some international agencies and bodies including the International Council for Building Research Studies and Documentation (CIB) are involved in solving the problem and have instituted specialised working commissions to deal with and advance knowledge on housing delivery strategies world wide.

In terms of technologies, modern urban settlement and housing delivery has each received a fair share of research and development inputs for the rich urban dwellers. The same degree of attention could not be said to have been paid to housing problems in developing countries where the cost of modern materials and construction technologies in the housing sector have forced even the rural poor to set aside the local housing construction materials and technologies and are helplessly trying to use imported materials and housing construction technologies which they cannot afford. Indeed, the housing situation is becoming more and more gloomy as a result of world population explosion coupled with the drift of the rural poor to urban centres in search for work, shelter and modern style of life in most developing countries. Within the last two decades there have been considerable national, regional and international research and development activities in some key areas in an attempt to evolve innovative approaches towards solving the problems of shelter and housing delivery. Areas requiring particular attention at national, regional and international R & D efforts include, socio-economic and cultural studies, revival and upgrading of traditional architecture and planning, research on housing policy, housing finance, land aquisition and cost implications, as well as housing delivery strategies adapted to the way of life of the beneficiary; development of local materials by simple and transferable technologies, educating the beneficiary on new obligations and responsibilities, setting up of small-scale rural industries and artisanal institutions, institutional structures for training artisans as well as national commitment to address the housing delivery problems especially for the benefit of the rural poor. A major constraint in achieving a break through has been the overwhelming flooding of markets in developing countries with foreign building materials and construction technologies and lack of internal strength to resist the pressure with alternative materials. Few countries can afford to continue importing enough foreign building materials and technologies, and the reality which is facing economically distressed countries today is the need to look within for local building materials and locally proven construction alternative strategies, and to formulate systematic educational programmes to effect a real change of the present outlook to overcome the false standards, prejudices and distrust of local building and construction materials, especially earthen materials as alternative housing construction materials. The first step in evolving any regional or national shelter or housing delivery policy is to identify the housing demands and needs. The solution to this problem lies in isolating the relevant key actors, factors and indicators and their interplays and to try to evaluate their importance and relevance. For example, some of the elements and factors that need to be defined at the local, national or regional levels in order to establish national or regional housing needs and the housing delivery capacities to meet the current demands are summarised in Fig. 1.1. These basic elements should emanate from serious national or regional statistical, social, economic and demographic researches. It is not the intention in this report to discuss all the detailed actors involved in housing delivery process. The objective of the project has been clearly defined, and attempt has been made to limit the study to the scope of the project objective; national follow up actions can take care of other aspects later.

World wide, earth building is not new; it is acknowledged that it is the oldest materials for housing construction. For example, results of Archeological excavations and information available from the United Naitons Educational, Scientific and Cultural Organisation (UNESCO) sources indicate that the great civilisations of Africa, and Latin America thrived on earth buildings. The present status of Timbuktu is a clear testimony of this. Indeed, earth building construction has been the realistic shelter delivery option for rural housing processes for centuries especially in the tropical and sub-tropical countries (e.g. Government of Belgium and United Nations Centre for Human Settlements (UNCHS-Habitat, 1984)). The problem of shelter for the homeless in developing countries was one of the three themes for long discussions at the 10th Triennial Congress of the International Council for Building Research Studies and Documentation (CIB, 1986) held in Washington DC from 22nd to 26th September, 1986. The overall theme of the congress was "Advancing Building Technology". Under the sub-theme on "Shelter for the Homeless in Developing Countries" which attracted delegates from most developing countries was addressed extensively such topics as innovative tropical housing research and development, housing construction materials, construction technologies, innovative designs, and production of low energy earth building components. Though many alternative building materials are being developed, the available literature appears to indicate that earthen materials pose the least problems in terms of technical, financial and housing delivery problems in developing countries if only science and technology is allowed to assist and R & D introduced to upgrade the current traditional setlement planning, earth building design and construction technologies (e.g. Fitzmaurice, 1958; Government of Belgium and Habitat, 1984; UNCHS (Habitat) 1986; UNESCO, UNCHS (Habitat) and CEBTP (France) 1987; Commonwealth Science Council (CSC) 1985; ESCAP, RILEM and CIB, 1987; CIB (1986, Vols.4&5); CIB and RILEM, 1983; Mac Henry, 1984; SKAT, IT and Gate, 1988). Since earth buildings have been the historical dwelling homes of man, the problem of acceptability does not arise (e.g. Hammond, 1984) and where it arises it has been removed through education and demonstration use for construction of public facilities such as vocational training institutions, workshops, schools, clinics, recreational facilities, religious worship places, community centres, etc. The literature is replete with the various construction technologies available to day for housing construction in earthen materials (e.g., UNCHS (Habitat), 1986; Craterre, 1979; UNCHS (Habitat), 1986; Government of Belgium and UNCHS (Habitat), 1984; Hugo Houben and Hubert Guilland, 1989; McHenry, 1984). Attempts have also been made to bring together in brochures both old (obsolete) and modern equipment for earth building materials production (French Agency for Energy Management, 1987; Murkeji, 1986; UNCHS (Habitat), 1986; Hugo Houben and Hubert Guillaud, 1989). Though divers methods of producing earth building construction components and housing construction technologies in earth have been identified and published (Fig. 1.2), a few of them have actually proved feasible in terms of economics and practical application by non-highly qualified craftsmen and artisans; these are adobe, wattle and daub, Atakpame and rammed earth. Progress in modern earth building construction has been slow due partly to the fact that local Architects refuse to design in earth while materials engineers and construction technologists are constrained by the existing building regulations which forbid earth buildings in urban areas. For meaningful contributions to be made to earthen building construction, there is need for science and technology inputs in the field of materials development, innovative architectural designs, settlement planning and adequate funding. It is extremely desirable that modern earth building development projects should be multi-disciplinary approached so that sociologists, demographers, physical and social planners, creative architects, soil, foundation and drainage engineers, structural and mechanical engineers will have to work in a team to realise large-scale schemes. For example, development of appropriate machines for producing earth building components is far from being resolved. Most importantly, architectural design of earth buildings should be recognised and taught at the Faculties of Architecture in our local Universities. For extreme climatic conditions or and areas prone to natural disasters such as earthquakes, flooding and hurricanes the adverse effects of these natural disasters should be designed for; ONE PARTICULAR AREA IS TO PLANT TREES TO CONTROL ADVERSE EFFECTS OF RAINSTORMS AND TO RECOGNISE THE CONCEPT OF LIFE EXPECTANCY OF ROOFS.

There is also the need for building instrumentation for performance monitoring of buildings, results will assist in improving current building regulations, materials specifications, standards and codes development and practices as well as clearly identify qualitative and quantitative impacts of the intrinsic and extrinsic indicators and factors including such elements as earth buildings, durability, reliability, resistance to natural disasters, the physical/biological milieu, extent of promotion of the soil-plant relationships and environmental hygiene, promotion of the physical/biological enviro-resources, the social milieu, affordability, acceptability, and habitability (e.g. Ukot Uma, 1985). The way in which these factors and parameters inter-relate and interplay in the earth building delivery process with special reference to the African circumstances and situation have been succintly discussed elsewhere (e.g. Okot Uma, 1985) and illustrated in Fig. 1.1.

1.1 COMPONENTS AND OBJECTIVES OF THE PROJECT

Though the project falls under the broad area of "Earth Technology for Building Construction", it concerns a specific tropically weathered soil group, namely Lateritic Materials. These are reddish soils formed under specific geological, climatic and drainage conditions and mainly found within the tropics of cancer and the capricorn. In terms of scope and content, the project presents itself as the first phase of long-term lateritic materials characterisation, including their improvement and the development of the design (Architectural design) construction and maintenance of the buildings.

The overall objective of the research project is to carry out research and development activities for the realisation of liveable and durable low income lateritic houses in Ghana. The specific objectives of the project are as follows:

(a) To carry out some studies to reconfirm the properties of the dominant lateritic materials from the four climatic zones of Ghana.

(b) To evaluate the performance of existing traditional low income lateritic houses.

(c) To establish criteria for selecting suitable lateritic materials for the construction of adobe blocks and rammed earth walls.

(d) To develop small-scale technologies for the production of lateritic stone and lateritic soil-lime locally produced blocks at affordable prices.

(e) To develop improved design and construction techniques of low income houses by self-help, that are acceptable and affordable to the beneficiary; and

(f) To develop standard specifications and codes of practices for the construction of lateritic houses, through self-help.

2.0 GEOGRAPHICAL AND DEMOGRAPHIC DATA AND HOUSING STATISTICS ON GHANA

Ghana occupies an area of approximately 240 square kilometres, with the population of about 14 million as at 1986. It is one of the small West African countries having common boundaries on the Eastern side with the Republic of Togo, North with Burkina Fasso, West with la Cote d'Ivoire and South by the Gulf of Guinea. The location of Ghana in the context of West and Central African countries is illustrated in Fig. 2.1. Administratively, Ghana is divided into 10 regions (Fig. 2.2). The population density distribution as at 1984 is given in Fig. 2.3, and the distribution in terms of rural urban dwellers in the ten (10) regions is summarized in Table 2.1.

The average annual population growth according to the latest statistical information (see Table 2.2) is around 2.6%. Like any other distressed developing country, Ghana is facing acute housing shortage due mainly to inability to substitute the imported building materials with locally produced ones. One of the problems hindering the use of local materials for building construction is non-availability of local cheaper and equally durable substitutes. The country so heavily relied on the use of very expensive imported building materials which she cannot afford now to import due to shortage of convertible currency. As a result of the above stated causes the national housing delivery capacity is unable to meet the needs. For example, in 1984 the annual housing delivery capacity was 28 units in the public sector as against the demand for 70,000 units. In 1989, the delivery in the state sector fell to as low as 12,000 units. This disparity in capacity to deliver against the demand has caused the occupancy rate of 10 to 9.5 between 1960 and 1970. The recently published housing delivery Action Plan envisages the supply level of 133,000 housing units by the state sector per annum for the next 20 years in order to meet the total national needs. The statistics is fairly ambiguous in whether these figures relate to the total national demand and proposed supply action plan or we are only talking about the urban situation. Irrespective of what the figures relate to, the information on the ground indicates that the rural population takes care of over 90% of their housing needs, but the quality of these houses are very poor, and recent storms and excessive deforestation have eliminated protection of the houses against the adverse effects of the driving rain and storms. The result is consistent decline in the rural housing stock while the population continues to grow. The drastic increase in the local market of foreign building materials and components, and labour costs between 1978 and 1987 are illustrated in Figs. 2.4 and 2.5.

By 1982, the majority of Ghanaians had realised that they cannot afford even two bedroom houses constructed with imported building materials. Indeed, the trend of costs of sandcrete walled and aluminium sheet roofed buildings with moderate fitting levels have shot up so much (Fig. 2.6) that there is the need to look within for alternative local building materials, design options and construction technologies. The research findings of the Building and Road Research Institute which have been totally ignored in the past are beginning to attract acceptance for application in low income housing. Simple demonstration building projects and comparison of prices have established (fig. 2.7) that earth buildings can be very valuable substitutes as long as they can also be relatively durable. However, the high cost saving in walling characteristic of earth buildings cannot be applicable to both timber framed houses (fig. 2.8) due to the high cost of processing the wood into building components. There is also an unjustifiable prejudice against timber houses in terms of their susceptibility to fire burning them, or subterrenean termites destroying them. Research findings available indicate that these prejudices are unjustifiable. The attractive alternative of using burnt bricks is yet to take root due to the high cost of the bricks and the high labour cost of laying the bricks since it is time consuming and hence expensive. The rural walling and roofing materials utilization positions as at 1960 (Ministry of Works and Housing, Housing Conditions Census for 1960) are illustrated in Tables 2.3. In the National Housing Policy and Action Plan (1987-1990; Ministry of Works and Housing, 1986), targets for various building materials development as well as the cost implications are summarized in Tables 2.4 and 2.5.

3.0 ELEMENTS OF THE NATIONAL HOUSING SITUATION AND NATIONAL ACTION PLAN FOR THE PERIOD 1997-2005

The existing situation in terms of actual and projected housing delivery outputs by the private and the state sectors are summarized in Table 3.1. The proposed strategies and generation of resources to deliver the required number of housing units are also given as follows (Ministry of Works and Housing, 1986):

(1) Delivery Target Groups

i. Low Income Group

ii. Medium Income Group

iii. High Income Group

iv. Special Groups like hospitals, prisons, military, etc.

(2) Materials Development Programme

Government to encourage development of the following building materials (through investment incentives) and strengthening of the laboratories and materials production capabilities.

a) Roofing Materials

b) Structural and Masonry binders (cement, lime, pozzolana)

c) Walling Materials (clay and stabilized soil brick and block)

d) Primary Finishing materials.

(3) Manpower Development

a) Educational Institutions dealing with building to be revitalized to produce adequate skilled personnel; BRRI, FPRI, DHPR(UST) to organise in-service training programmes.

b) Human Settlement Training Centre for middle level personnel to be revitalized

(4) **Research and Development Needs**

Major areas to be given serious future attention:

a) The improvement of low level rated materials;

b) Settlement/erosion control and construction of prototype houses;

c) Identification of local sources of structural and masonry binders;

d) Building cost information studies;

e) Building construction practices improvement studies;

f) Standardization of building design components;

g) Increased utilization of timber in building.

Note in Tables 2.4 and 2.5 (Chapter 2) that in the projections for materials development and production requirements for the construction of sufficient number of houses, local materials development has not received significant anticipated inputs. Indeed, it is not mentioned at all with what type of materials we hope to attain the rural housing delivery targets. Apart from local timber and timber components, lime, pozzolana and brick production promotions, no mention has been made of say the use of natural stone, and the abundantly available lateritic materials as viable sources of local building materials development. It is in the light of this omission and the potentialities presented by lateritic materials utilization for local building materials development and production that the "Laterite Housing Project" presents itself as a potential means of providing rural low cost walling and perhaps roofing materials alternatives in the national rural housing delivery plan not only on short-term or adhoc basis but also as materials that need to be studied further for the production of new low energy housing construction materials in the future, given adequate inputs for increased R & D work to be carried out in the national Research and Development institutions.

4.0 REVIEW OF DEFINITION AND NOMENCLATURE ON LATERITE MATERIALS

Lateritic materials are the most common reddish tropically weathered soils and pedogenic surface deposits occurring in Australasia, Africa and South America yet wider differences of opinion exist in regard to their identification and classification than for any other soil type. The existing chemical, morphological, geologic-pedological and geotechnical information concerning lateritic materials indicate that the terminology used to describe them is not standardised and, consequently, numerous inconsistencies have developed in the identification, classification and nomenclature of these lateritic soils.

The literature on tropical weathering and the formation of lateritic materials is concerned mainly with the chemistry, morphology and the mineralogy of the processes. The complexity of the subject is reflected not only in the extent of the literature but also in the wide differences of opinion even over such basic question as the definition of laterite.

The term "laterite" was apparently first suggested by Buchanan (1807) to describe the reddish ferruginous, vesicular, unstratified and porous material with yellow orches occurring extensively in Malabar, India. The freshly dug material was soft enough to be cut into brick/block with iron instruments but rapidly hardened on exposure to air and fairly resistant to the weathering effect of climate. This material was locally used as brick for building and was hence called "laterite" from the latin word "later" meaning brick.

Fermor (1911) developed a comprehensive system of nomenclature of laterite soils on the basis of the relative contents of the so-called laterite constituents (Fe, Al, Ti and Mn). Similar chemical nomenclature was proposed by Lacroix (1913), who divided lateritic materials into (a) true laterites; (b) silicate laterites; and (c) lateritic clays.

Alexander and Cady (1962) defined lateritic materials as follows: "Laterite is a highly weathered material, rich in secondary oxides of iron, aluminium, or both. It is nearly void of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. It is either hard or capable of hardening on exposure to wetting and drying".

In terms of textural characteristics some authors confined the term "laterite" to one textural group of these materials. For example, Nixon and Skipp (1957) suggested that only the concretionary coarse materials should be called laterites, while the fine-grained materials should be referred to as red clays or latosols. Nanda and Krishnamachari (1959) on the other hand have restricted the term "laterite" to only the massive concretionary rock-like materials also known as cuirasse (Remillon, 1967).

To overcome the problem of defining lateritic soils texturally, Nascimento (1959) suggested the use of the term "lateritic" in conjunction with the standard grain size groups. This appears to be fairly sound because all lateritic materials though very variable and erratic texturally, do contain all soil fraction sizes; boulders, cobbles, gravel, sand, silt, and clay as well as the massive concretionary stones.

Apparently, the problem of defining lateritic materials is very complex defying agreement among geologists, soil scientists, and soil engineers. Though it is important to recognise the difference between lateritic and non-lateritic materials and further to recognise the difference between types of lateritic materials, the real consideration for identification and evaluation of these materials for engineering purposes is not "what is its name" but what are the significant geotechnical characteristics and engineering behaviour (Vallerga et al. 1969).

To overcome the above indicated difficulties, Peck (1971) proposed the term **"reddish tropically weathered materials"** irrespective of the details of the degree of their weathering, and irrespective of the presence or absence of concretionary crusts or cuirasses.

However, for the purpose of this study, the term "lateritic soil" "laterite soil" or "lateritic materials" are used to describe all the reddish residual and non-residual weathered materials which genetically form a chain ranging from decomposed rocks, through clays to the sesquioxide rich concretionary stones. Such a definition would include four of the Great Soil Groups defined by Thorp and Smith (1949) as follows:

(1) the reddish brown lateritic soils

(2) yellowish brown lateritic soils

(3) lateritic soils, and

(4) groundwater lateritic soils

The first three are zonal soils of forested warm and tropical regions with well-developed profiles in which the dominating influences of climate and vegetation are expressed. The ground-water lateritic soils is an intra-zonal soil and the profile shows the influences of imperfect to poor drainage and great age on the process of soil development. Genetically, two types of laterite materials have been identified in Ghana in terms of chemical characteristics.

At one end is the continously wet climatic zone aluminous (bauxitic) materials and at the other end we have the dry or alternate dry and semi-humid climatic zone iron rich (ferrugenous) ones. Each of the two groups exist in a large succession of reddish materials of weathering starting with fresh rock and ending with sesquioxide rich pedogenic rock. Changes in the physico-chemical weathering processes are accompanied by chemical, mineralogical and physical transformations; these processes come under the terms weathering and evoltion of lateritic soils.

The term "laterite" or "lateritic" as used in this publication is therefore neither definitive nor indicative of any chemical, physical or morphological characteristics whatsoever, the key parameters are the genetic and geotechnical characteristics which influence materials behaviour in buildings in relation to given environmental conditions. Of all the materials occurring in the tropical belt the reddish lateritic materials constitute the most abundant, and they have attracted considerable pedological, geological and in recent years, geotechnical investigations. The pedological and geological studies have provided very useful background information for the engineering investigations and utilisation of these materials in building and road construction. The geographical distribution of these materials has not to-date been fully defined but some information available indicate that for the time being their major global location areas are as given in Fig. 4.1.

Africa has a fair share of the distributioin of these materials as shown in Fig. 4.2. Note that it occupies a wide area of West Africa also and therefore has great potential for economic use. Considerable investigations and literature studies have given broader and finer definition of the distribution of these reddish soils formed over different parent materials under wide geographical and drainage conditions in West Africa. This is the result of a major work published on West African soils from pedological viewpoint and published elsewhere (Ahn, 1970). The morphology and topography have been found to be very useful tools in locating construction materials and soils. In the case of locating lateritic materials geomorphology has been particularly helpful.

Geomorphology which is concerned with landform, materials and their related processes, together with climatic conditions constitute a very useful tool for regional or local field identification and location of soils and other constructional materials. Geomorphological map portrays the forms of the surface, the nature of properties of the materials of which these are composed, and indicates the kind and magnitude of the inter-related processes of climate, geology, soil forming processes, engineering geological and pedological features all of which are useful for proper integrated regional economic development process. Indeed, geomorphological maps also provide an integrated and comprehensive statement of landform and drainage. They contain information of considerable value in land use relating to development planning, hydrogeological, civil, foundation, highway engineering as well as earth building technology development.

Within the tropical belt, Bunting (1965) used climo-geomorphic concepts to map genetic soil types. The same tool has been used with considerable success by Maignien (Maignien, 1966) to map laterite materials in West and Central Africa and to identify them in terms of textural, morphological and chemical characteristics (Table 4.1). Laing (1964) also used aerial photography to identify these materials making use of such indicators as topography, drainage, erosion pattern, grey tone and vegetation. This allowed the laterite materials to be identified in terms of texture and for predicting the environmental implications of their exploitation and use in the development processes. Though chemically, various types of lateritic materials have been reported in various parts of the world (e.g. Gidigasu, 1976) two types appear to be predominant in West and Central Africa, namely, the aluminous and the ferruginous types of lateritic materials. The main features of the two types of lateritic material occurring abundantly in West Africa are summarized in Table 4.1. These materials differ also in some respects in terms of geotechnical characteristics and engineering behaviour.

The most single property for identifying lateritic materials is colour. The specific colours of lateritic materials have been identified with mineralogical composition (Table 4.1); micro and macro structure development has also been noted as playing important role in the morphological and geotechnical characterisation of lateritic materials. Though not specifically for lateritic materials, the main processes involved in the development of soil structure generally in relation to the environment and forming factors have been discussed by Mitchell

(1976) who summarised the processes of soil structure development in Fig. 4.3. It has indeed, been realised that the fundamental engineering behaviour of most residual tropical soils and pedogenic materials depend to a great extent upon the nature of the micro/macro structure of the material (e.g. Mitchell, 1976; Townsend et al, 1969, 1971; Wallace, 1973; Lohnes and Daniel, 1973).

The mineralogical and chemical transformations associated with the formation of lateritic materials have also been studied by many geologists, pedologists, geo-chemists and soil-mineralogists. In recent years, attempts have been made to rationalise the mineralogical processes of lateritisation and, though few agree on a single hypothesis, the proposal made by Schellman (1979) appears to have some promise (Fig. 4.4). The various processes of weathering of natural rocks and transformation to lateritic materials have also been shown to have significant geotechnical implications. For example, the physical process of lateritisation in the West African environment is summarised in Fig. 4.5. Lohnes et al (1976) have established some relationships between the stages of lateritisation processes and the implications in terms of variations of some significant geotechnical properties (Fig. 4.6). This constitutes very valuable contributions to pedological lateritic materials studies for engineering application.

Lateritic materials have been reported to be of pedogenic in nature and differ significantly from the natural temperate zone materials. In the same group of pedogenic materials are such materials as calcretes (Netterberg, 1971), silcretes and ferricretes, etc. (e.g. Aitchison and Grant, 1967). The main differences between the natural soils and pedogenic materials are illustrated in Table 4.2. Fermor was one of the first to attempt the classification of lateritic materials for geological and pedological purposes using the chemical features as the criteria (Table 4.3). To illustrate the diversity of chemical composition of lateritic materials, Table 4.4 has been reported (see Prescott and Pendelton, 1952).

Another contribution to the characterisation of lateritic materials related to their response to degree of dehydration by heating, and consequent loss of weight. Typical minerals in lateritic materials have been identified through dehydration curve characteristics (Fig. 4.7). Differential thermal studies on lateritic materials have also revealed interesting results, some of which are shown in Fig. 4.8. It has been amply shown that lateritic materials are unique materials with characteristic morphological, colour, structure, chemical and mineralogical composition. Fig. 4.9 illustrates an attempt to classify tropical pedogenic stone characteristics.

5.0 FORMATION AND DISTRIBUTION OF LATERITIC MATERIALS IN WEST AND CENTRAL AFRICA.

5.1 CLIMATE AND VEGETATION OF WEST AFRICA AND GHANA

Data on the rainfall, temperature, vegetation and relative humidity of West and Central Africa including Ghana are summarised in Figs. 5.1 to 5.4 and Table 5.1. Note that in the case of Ghana the distribution of vegetation types appears to be a function of the rainfall distribution pattern. In the coastal savannah zone rainfall distribution is below 1000mm per year; values of 1000mm-1400mm per year mark the deciduous woodland savannah zone, 900mm-1650mm per year for the semi-deciduous forest zone and greater than 2000mm per year characterise the wet tropical rain forest. However, these are not definitive of the climate and Thornthwaite (1948) has proposed a more rational classification in terms of moisture index. The latter is a parameter calculated on the basis of rainfall, temperature, prevailing wind, vegetation cover, evapotranspiration, and water shortage capacity of the soils and is a measure of the overall availability of water to soil. Average values of the key environmental/climatic conditions are summarised in Table 5.1.

From monthly figures of precipitation and evapotranspiration it is possible to indicate monthly conditions of water surplus and deficiency, while the potential evapotranspiration is calculated on the basis of mean monthly temperature. The Thornthwaite Moisture Index (MI) is then calculated from the following expression,

$$MI = \frac{100 \sum D - 60 \sum d}{\sum Ep}$$

where D = monthly surplus of water, d = monthly deficiency of water (inches) and Ep = monthly potential evapotranspiration (inches). Thornthwaite has classified climatic type in terms of moisture index as follows:

Perhumid	100+
Humid	20 tO 100
Moist sub-humid	0 to 20
Dry sub-humid	-20 to 0
Semi-arid	-40 to -20
Arid	-60 to -40

Having determined the moisture index of limited reference stations it was possible to produce a map showing moisture index zone boundaries. Note that moisture-index map (Fig. 5.5) correlates fairly well with the climatic vegetation map (Fig. 5.3), and hence justifies the use of the climatic vegetation map as a basis for identifying laterite weathering conditions and nature of the lateritic materials. The climatic zones influence the distribution of lateritic soils in Ghana and also influence the traditional architecture and construction technologies of earth buildings in the various parts of the country.

5.2 GEOLOGY OF WEST AND CENTRAL AFRICA

In order to have some idea on the distribution of laterite materials in Ghana, it is necessary to start with some information on the parent rock types. Most of the important rocks are respectively gneiss, granites and phyllites, and granite, sandstone, shales and mudstones. The morphology and physical features have been shown (e.g. Maignien, 1966; Ahn, 1970; n

Brammer, 1962) to be primarily responses to the geologic structure and the rock types. For example, most of the hills and ranges consist of hard resistant rocks such as quartzites, whereas the valleys and lower grounds are carved out of softer rocks such as shales, sandstones, phyllites and schists (Bates, 1962).

The simplified geological map of West and Central Africa and and in more detail of Ghana, are shown in Figs. 5.6 and 5.7. Note that the geological system of West Africa is generally uniform, and given the same environmental, climatic and drainage conditions one would expect the formation of similar lateritic materials (e.g. Ahn, 1970).

5.3 SOIL FORMING PROCESSES AND NATURE OF LATERITIC MATERIALS IN GHANA

The nature and genetic characteristics of lateritic materials in Ghana are influenced mainly by the environmental factors such as climate, geology, geomorphology, and drainage conditions, all of which determine the nature of the profiles (morphology), the physical features, the chemistry and mineralogy of the soils. For example, the nature of the rock determines the texture of the soil, while the internal drainage conditions and nature of the mileu (pH) determine the chemistry, the mineralogy and the physico-chemical properties. West African soils formed over basic igneous rocks in arid environment and poorly drained areas have a characteristic black and brown colour with the clay mineral being predominantly montmorillonite (Stephen, 1953; Nye, 1954, 1955). These soils are heavy and plastic when wet, hard and compact when dry, cracking to varying depths depending upon the proportions of the montmorillonite clay mineral present and the differential dessicating forces. Soils formed in high rainfall humid climatic zones over igneous and metamorphic rocks are subject to intense leaching, leading to the end products comprising of highly compressible clays and loamy soils.

In granite areas of the wet sub-humid to dry sub-humid climatic zones the leaching out of soluble feldspar and colloidal matter from the decomposed rock promote the formation of soils exhibiting collapsible structure.

The broad weathering conditions defined mainly by parent rock type, the climatic and drainage conditions form a sound basis for characterising Ghanaian soil systems.

5.4 SOIL GENESIS AND EVOLUTION OF LATERITE MATERIALS IN GHANA

Various environmental factors intervene in the genesis and evolution of soils. The chemical processes of a residual laterite weathering of a biotite - orthoclase-quartz-rich granite under the acid soil conditions of the moist sub-humid climatic zone of Ghana is given in Fig. 5.8. It has been established that topography and drainage condition play significant role in laterite soil formation in Ghana. Two theories of primary and secondary weathering (laterisation) have been proposed for the two types of laterite soils found in Ghana. One of these (Cooper, 1936) involves the removal in solution through leaching of combined silica and bases with the relative accumulation of sesquioxides. The other concept (Hamilton, 1964) (Fig. 5.9) attributes the formation of laterite profiles to the upward movement of sesquioxides with underground water to form high-level laterites and the lateral movement of sesquioxides with ground water to form middle slope laterites and again lateral movement of sesquioxides downslope to form low level laterites. Studies (Bhatia, et al., 1970, and Gidigasu and Bhatia, 1971) of lateritic soil profiles suggests that both theories have validity and depend upon the source of sesquioxides, local topography and internal drainage conditions. Very important also is the development of soil structure. The laterite materials formed in West and Central Africa appear to be stable under the following conditions:

(1) availability of sesquioxide-rich parent material

(2) average annual rainfall of around 1000mm or more

(3) existence of neutral or acidic soil conditions

(4) good internal drainage and soil permeability; and

(5) alternate wet and dry season.

The processes of lateritisation thus involve chemical, mineralogical, structural and morphological transformation of the parent rocks through soils to lateritic stone and this involves certain geotechnical implications. The main changes in geotechnical properties induced by lateritisation processes are summarised earlier (see Fig. 4.5) and specific geotechnical characteristics resulting from this for Ghanaian soils have been reviewed elsewhere (e.g. Gidigasu and Kuma, 1987). The distribution of lateritic materials in West Africa is shown in Fig. 5.10.

5.5 MORPHOLOGICAL CHARACTERISTICS OF LATERITE SOILS IN GHANA

Laterite profiles are characterised by 4 main horizons as follows. Generally, a humus-stained topsoil varies in thickness from 7mm to 25mm, according to the climatic-vegetational zone and local topography. The B-horizon is a zone of accumulation from the A-horizon during the rainy season and the C-horizon in the dry season through evaporation. In the laterite areas the B-horizon is rich in sesquioxides (mainly Al_2O_3 and Fe_2O_3), and in the tropical clay profiles it contains calcium-carbonate concretions. The B-horizon varies in thickness from about 0.6m in the middle slopes of the local topography to over 10m of old laterite stones as peneplain remnant plateau surfaces. The C-horizon is essentially one of weathered parent rocks from which soluble minerals are moved up to the B-horizon. While it barely attains 3m over shales in the arid climatic zone, it exceeds 50m over granite and phyllite in the humid zone. The D-horizon is the unweathered parent rock. A typical lateritic soil profile is illustrated in Fig. 5.11. The variation of soil colour with local topography and the general morphological, chemical and mineralogical characteristics of the pedological great soil groups identified in Ghana are reported elsewhere (Hamilton, 1964; Brammer, 1962; Ruddock, 1967; Gidigasu, 1976, and Gogo, 1990); these are shown in Figs. 5.12 and 5.13. In order to minimize the effect of depth factor in the study, the samples were taken from depths which did not exceed 3m below the ground surface where the degree of dessication was assumed to be nil or approximately the same. Local topography exerts a strong influence upon the nature of soils. For example, upland soils generally are residuals and more reddish whereas the valleys and lowlands are covered by non-residuals and less reddish materials (Gidigasu, 1976). Mature laterite materials constitute another genetic soil group and is either upland residual (primary) laterite or lowland sesquioxide-impregnated (secondary or terrace) non-residual crusts. The chemistry and mineralogy of the lateritic materials also vary with topographic situations (e.g. Nye, 1955). The chemical characteristics of lateritic materials are illustrated in Fig. 5.14.

5.6 BASIC GROUPING OF SOILS IDENTIFIED

On the basis of field studies and preliminary laboratory examination of the texture and structure of the most important genetic soil types present in Ghana, lateritic materials were grouped genetically and texturally as shown in Fig. 5.14. Among the fine-grained soils which were not considered in the study are non-laterites, collapsible sands over sand-dune formations pedologically known as regosols (Brammer, 1962). Also freshly deposited silty clays in the coastal lagoons and the organic pans or peats occurring in regosolic profiles were omitted from the study. The purpose has been to concentrate on the reddish lateritic materials which occupy about 70% of the surface of Ghana (e.g. Brammer, 1962) as forest oxysols, forest and savannah ochrosols and groundwater laterites. For the fine-grained soils the degree of laterisation and desiccation can be roughly assessed visually on the basis of colour and structure (e.g. Coleman et al, 1964; Coleman, 1965). For the purposes of further geotechnical evaluation, lateritic materials identified in Ghana have been genetically grouped into three categories as shown in Fig. 5.15 and Table 5.2.

6.0 EARTHEN BUILDING MATERIALS IN RURAL GHANA

6.1 NATURAL STONE AND BOULDERS

Rock boulders and cobbles constitute important building construction materials in some rural areas of Ghana. This applies mainly to quartzitic and granitic rock areas along and within the Akwapim, the Tarkwaian and the Togo ranges. Clay has been used traditionally as mortar but recently cement or a mixture of both have replaced clay for raising walls with natural stone pieces (Fig. 6.1). A number of church buildings have also been built in the country applying more scientific methods of cutting rocks into blocks and using sand-cement mortar. As regards the traditional use in the rural areas there is scope for scientific intervention to improve the site preparation, the foundation type, the raising of the walls and the maintenance of the ground around the buildings through, say, providing concrete apron or grassing the compound to stop excessive erosion. The areas where stone materials are abundant erosion of the foundation is a major problem. United Nations Industrial Development Organisation (UNIDO) (Shadmon, 1975) undertook a feasibility study into the use of cut rocks for general construction in Ghana and the preliminary survey revealed that it had great promise. Indeed, UNIDO sent rock winning equipment for primary studies to be started and this was to be followed by a training scheme for artisans and craftsmen (rock cutters and stone block layers) to promote the use of dimensional stone especially in urban housing construction, however, there was no follow up.

It appears that this area deserves further research and development activity but is obviously outside the scope of this programme. The main constraint to the use of natural stone blocks is the potential danger of rapid weathering of some of the igneous rocks in the walls and the washing away of the clay mortar. Scientific investigation of the quality of rocks that should be used to ensure long term integrity of buildings in Ghana, should, however, be considered as a separate project, say, by the geological section of the Building and Road Research Institute.

It would appear, however, that natural stone materials are grossly under-utilized. Considering the large and abundant market, it is important to enter into this field without delay. Large reserves of natural stone suitable for building construction have been observed and are reported in the memoirs of the Geological Survey and other international bodies (e.g. Shadmon, 1975). The present shortage of cement, and the increasing prices of residual oil to fire clay bricks, make it imperative for Ghana's housing construction industry to use the great potential that can be provided by a well-planned exploitation of natural stone reserves. Shadmon (1975) proposed the setting up of a stone centre attached to the Building and Road Research Institute to provide an awareness of the potential and importance of stone resources. The Stone Centre was to demonstrate modern exploitation, quarrying, processing and marketing methods now available for development of these natural assets both with the simplest possible equipment and, where required and necessary, most sophisticated production methods.

The services of such a Stone Centre would be available to the industries as well as to the Government according to their specific requirements; for instance, on the one hand for quality control for the benefit of industrial interests, and on the other hand for legislative and inspection purposes required by the state.

6.2 WATTLE AND DAUB

Perhaps the most popular rural housing technology in the cocoa and other cash crop growing areas of Ghana is the wattle and daub built by the farm labourers in the poorer regions or by the migrant labourers from the neighbouring countries. The wall construction method consists of a network of bush sticks or palm branches tied horizontally to larger poles vertically fixed to the ground, with wetted soil (generally clayey soil) used to fill the gaps in order to form a wall and provide finished walls surface. The roofing materials are either thatch, palm branches or cocoa leaves, etc. A typical wattle and daub walled building is shown in Fig. 6.2. This method of construction has its limitations since it involves the depletion of bush sticks which may later form larger trees for use as fuel or construction timber in the current drive to use secondary species of timber for housing in Ghana. In terms of durability it is perhaps the weakest earth building type and in areas where rainstorms are frequent they are unable to stand them. However, in the more arid and drier areas where forest and or vegetation constitute wind brake to protect them from the severe windy storms the houses could live up to between 30 to 50 years (Gidigasu, 1987e). The main hazards here are termites which destroy the vertical and horizontal wooden or bamboo network and cause the building to collapse. Severe rains also soften the walls and do cause erosional degradation to the earth foundations. The more durable and perhaps sophisticated traditional rural earth walling technologies are the Atakpame and the adobe systems. Rammed earth walling has been tried in isolated places but abandoned because of the problem of advanced formwork production as against the comparatively easy methods of raising Atakpame and adobe walls.

6.3 ATAKPAME AND ADOBE BLOCKS

For the purpose of this study Atakpame walling is a process in which raw soil is thoroughly mixed with water and skillfully used manually to raise walls by average lifts of 0.3m followed by another layer when the first one is dry enough to support the next lift. History has it that Atakpame and Adobe were used in 1100 A.D. in the construction of the then Centre of African learning and civilization in Timbuktu and some of the two or three-storey buildings constructed with these materials are still standing today.

Apparently, African housing construction tradition is basically soil based. There has beeen no problem with acceptability of this type of building because they have evolved from within historically and research should be aimed at upgrading the planning, design, construction and protection aspects as well as providing water and other sanitary facilities to improve the quality of rural life in Ghana.

As regards the reliability and durability, some of the crudest construction using these materials have been in existence in Ghana for over 60 years (Fig. 6.3) especially in the dry semi-arid to dry sub-humid climatic zones. They also perform fairly satisfactorily in the wet sub-humid and humid areas except that their life-span is shorter due mainly to the adverse effects of erosion forces of the high driving rainfall.

Any contribution to low-cost housing in Ghana should be geared toward promoting Atakpame, adobe, rammed earth and local lime lateritic materials products (blocks and bricks). The most crucial area requiring attention is of course, the upgrading of Adobe and introduction of rammed earth for walling. What needs to be done is to approach the problem more scientifically and to develop, design, construction and maintenance specifications for the walls, the foundations and the compound of the houses. Contrasting appearances of poorly built, unplastered and unpainted and technically planned and properly constructed, plastered and painted Atakpame and Adobe buildings abound in Ghana to show that appropriate technology inputs is all that is required.

It is obvious that comfortable houses can be produced from Atakpame and adobe walling technologies by introducing expertise training into the field to upgrade the design, construction, wall protection and maintenance strategies.

Indoor climatic studies should also be undertaken as there is evidence that Atakpame and adobe houses are cooler, this is a blessing to the rural poor who can only afford to build with lateritic materials which are suitable soil deposits for this purpose in many West and Central African countries.

6.4 LATERITIC STONE BUILDING

Laterite stones occur widely in the tropics within most geological formations and climatic conditions (Bhatia and Hammond, 1970; Gidigasu, 1970; Maignien, 1966). These materials occur either as fairly soft materials capable of hardening on exposure to air or they are rocklike insitu depending upon the topographic site, the climatic zone and the chemical composition (e.g. Gidigasu, 1976). The geotechnical properties of typical lateritic stones and boulders in Ghana have been evaluated and results reported elsewhere (e.g. Bhatia and Hammond, 1970). Comparing the aggregate properties with that of sound aggregates (e.g. Road Res. Lab., 1952), it was found that laterite aggregates can also be used for the manufacture of concrete blocks for civil engineering construction (e.g. Gidigasu, 1980). For example, fairly high crushing strength values have been reported for some lateritic stone in Africa. The uniaxial crushing strengths reported for typical West and Central African lateritic rocks vary between 196.8 and 316.4 kg/cm^2 (Shergold, 1945) while values reported for typical Ghanaian ferrugenous laterite stone range from 31.6 to 175.8 kg/cm^2 (e.g. Obeng, 1970). Concrete blocks were also manufactured from laterite stone aggregates from some sources in Ghana. Aggregates made to conform to grading specifications for 12.7mm and 38.1mm maximum aggregate sizes; and concrete cubes prepared with mix design of 1:2:4, and water cement ratio 0.5 gave fairly high crushing strengths. Cubes were prepared, cured for 24 hours of storage in wet sack followed by immersion in water for the remaining curing periods before testing. Average test results were reported for 3 cube tests for each aggregate after 7, 28, 60, 120, 180 and 360 days. It was noted that on the average, the 28 days cured concrete strength of 210 kg/cm^2 can be obtained if care is taken to select the hard lateritic stones.

Figure 6.4 shows a typical lateritic stone rural building while Fig. 6.5 also illustrates the well-designed and constructed residential and church buildings constructed with local lateritic stones.

Table 6.1 summarizes roughly the predominance of the various soil and rock based rural houses in Ghana in relation to the climatic zones. It is noted that only Adobe is popular in the humid zone not only because of lack of laterite stone but also because of the damage that the high rainfall of over 2000mm per annum can inflict on say wattle and daub and Atakpame buildings. Rammed earth and lime soil stabilised blocks may provide alternative durable rural walling materials for this humid climatic zone of the country.

7.0 FAILURE PATTERNS OF LATERITIC HOUSES IN GHANA AND THEIR FIELD PERFORMANCE EVALUATIONS

The life expectancy of soil-based buildings in Ghana depends upon a number of factors. The most important ones being the type of material, the relevance of the technical evaluation process; the technology of construction, as well as the resistance to the destructive environmental hazards of the climatic zone in which it is built. For example, earth buildings have longer life span in the drier areas than in the wet humid zone. The life of the buildings also depend upon whether or not they were handled by inter-disciplinary group of professional specialists such as planners, architects, quantity surveyors, designers, materials and foundation engineers, qualified contractors and also how far regular maintenance works have been carried out on the buildings over the years. Where specialists have not assisted in the design and implementation of the project but regular remedial and maintenance works were carried out on the buildings, the life of some of the earth-based buildings have been up to over 80 years. Where specialists have not been consulted and this is generally the case in the rural areas, the houses have quickly deteriorated in the adverse environmental conditions, and failures including excessive weathering and degradation of the walls, ground/compound erosion around the houses leading to short life of the buildings have taken place. In some cases, it has led to loss of precious lives and property. Apparently, in upgrading existing traditional technologies for using Atakpame walling and Adobe blocks in housing construction, it is absolutely necessary to emphasise the role of inter-disciplinary technical assistance of professionals to the rural communities in the planning, design, construction, wall protection, proper roofing and development of proven maintenance specifications for the buildings and the surrounding grounds to also ensure healthy sanitary environment. Good ventilation and adequate green vegetation between the buildings to ensure the general well-being of the dwellers is another important requirement. These are the challenges of future rural housing delivery technologies.

7.1 WEATHERING AND EROSION OF SOIL AND SOIL-BASED BUILDINGS IN GHANA

The greatest natural hazard in the tropics is the rapid weathering of rocks and soils including soil-based building materials in service.

In the drier areas the rate of deterioration of walls is not as rapid as in the humid areas. Earth building walls subjected to driving rain alternated with periods of droughts have their surfaces subjected to alternate swelling and shrinkage, allowing water to enter, including physico-chemical weathering and decay of the wall surfaces. It is, therefore, necessary to expect high costs of maintenance of unprotected Atakpame and Adobe building walls. The materials are not by nature durable and whether they have been improved through thermal stabilisation into burnt bricks and blocks, the danger of weathering, degradation, and erosion still exist. This aspect of building with soil and soil-based material therefore needs to be investigated scientifically and remedies found within the framework of this or any other future projects.

The Building and Road Research Institute has developed a method of mixing bitumen with clay for plastering earth buildings before white-washing them (Bawa and Hornsby-Odoi, 1965), and this has provided good plastering method over the years. This technology though successfully employed in some climatic zones has to be investigated further for wet humid zones as well. It will then be possible to popularise this useful method of protecting walls because performance studies have shown that, it is a very useful method of prolonging the life of earth buildings (e.g. Hammond, 1973).

7.2 MAINTENANCE AND REHABILITATION OF SOIL AND SOIL-BASED MATERIALS IN GHANA

As noted earlier, the chemical weathering, degradation and the erosion of earthen walls, the foundations as well as excessive erosion of compounds has led to the rapid deterioration of some rural and urban soil and soil-based building/settlements even though they may be well-planned and executed. For example, experiences gained since 1948 on the performance of a low cost soil cement housing scheme which was carried out by an inter-disciplinary and competent professional group has demonstrated, without doubt, the difference between the performance of well-maintained and un-maintained walls, foundations and compounds of these soil-cement low-cost buildings.

7.3 CRITERIA FOR SELECTION AND QUALITY CONTROL OF SOIL AND SOIL-BASED WALLING MATERIALS

Soil is by nature both complex and variable. However, because of its universal availability and its low cost of winning, it offers great opportunity for use as building construction material. The main problem is the selection of the soil type most suitable for the particular constructional work concerned in a specific environment. In building construction, the soil may be used in a raw state or may be modified in many ways, among which are chemical, thermal, mechanical stabilisation etc. Correct use of soil for building construction demands a clear recognition of which soil properties must be modified and this requirement is an important element in the decision regarding the method of treatment of the soil before used for the building construction. The significant properties of a raw or stabilised soil and soil-based buildings are consequences of inadequate control over each of these properties. Technical insurance against adverse conditions developing either in the course of design, construction or during the life of the building is also necessary. Some clayey soils swell or shrink with changes in moisture content. If the seasonal long-term moisture changes is not controlled, this may cause crack in buildings, breaking of underground service pipes, cause foundation heave, and economic loss. The preventive measures to these sources of building failures are achieved either through conversion of the soil to a rigid or granular mass, the particles of which are sufficiently strongly bound to resist the internal swell pressure of the clay (e.g. converting the clay to an effective sand or brick); or retard moisture movement within the soil by, say, blocking the pores. The bearing strength of most raw fine-grained soils is low when wet; however, air-drying in a low humidity environment produces hard materials. Burning at high temperatures will further convert the fine-grained soil to strong brick. For practical purposes the strength properties is of less importance in construction than resistance to deformation under load. Inadequate strength or resistance to deformation is a major soil problem in building construction and can lead to serious economic loss. A number of treatment options of soils to produce durable building materials exist, however, the choice of the method should be decided first through laboratory studies to assess the textural, chemical, mineralogical, physico-chemical and compositional properties and how these affect the economics of construction and long-term maintenance cost of the building in a given environment of expected natural or inflicted hazard.

Permeability of soil is another important property that should be controlled as this influence the amount of water that the soil can absorb. Hence, permeability has direct relationship to bearing capacity and potentials for moisture absorption and hence volume change and bearing strength properties. It is desirable that the permeability of soil-based building materials should be as low as possible. The allowable levels of permeability of building construction materials in relation to the use are given in appropriate building codes and specifications. For example, poor compaction of "adobe" can lead to high permeability. Secondly, poor firing of clay building products can also lead to high permeability, potential for high moisture absorption, weathering on exposure to humid tropical environment and eventually to erosion when subjected to driving rain. Measurement of permeability of soil-based building products both in the laboratory and in the buildings after placement in the wall is highly recommended in the process of quality control of the construction materials.

Durability is yet another key requirement of soil-based building materials. The resistance to the processes of weathering and erosion is a very desirable condition. There is a wide range of durability for raw and treated soil building materials and the upgrading of those with poor durability is most desirable. Poor durability can be a problem for both natural and treated (stabilised) soils and clay products. It is essentially a surface problem for the walls of "adobe" houses. Except for a few cases, there is a major deficiency in terms of lack of useful tests by which to assess the potential durability of raw soil or soil-based materials for housing construction. The American Society for Testing and Materials (ASTM, 1958) has developed a weathering test for stabilised compacted soil-cement essentially for pavement construction and a modified version has been proposed by the West African Building Research Institute (WABRI); Sperling, 1962). Because of this lack of internationally accepted procedure for evaluating the resistance to weathering of soil-based building materials, durability is one of the most difficult earth material evaluation problems the designers meet in various climatic and natural hazard prone environments.

A common reaction is to overdesign; even this can be neither economic nor even technically sound. It is possible, however, now to pre-assess in a general manner, poor chemical and water resistance of a soil and appropriate remedial stabilisation method applied. The selection of soil for building construction should be based on criteria that take cognisance of the above-mentioned significant parameters which influence the performance of buildings in a given environment.

7.4 ACCEPTABILITY OF SOIL-BASED BUILDINGS IN GHANA

It has been established (e.g. Hammond, 1983) that acceptability of soil-based building materials and building types should be viewed in a broad context than as at now. The problem of acceptability of earth as a material for housing in Africa is related, among other things, to technical, economic, social, cultural as well as institutional factors. The implications is that the human element, for example, is of major importance especially in mass and non-traditional housing process.

Apparently, there is the need for specialists in the fields of sociology, psychology, town and country planning, architecture, civil engineering, landscape planning and social welfare to come together and work in a team to define the technical as well as non-technical (i.e. socio-economic and cultural) dimensions of the scheme to ensure acceptability to the target groups. Development of settlements should also be guided by government specifications, standards and policy guidelines so that every aspect of the operation would meet certain acceptability criteria. For example, primarily, the health and social well-being of the target group should be borne in mind. Ignoring the social and cultural aspects of the target group may lead to failure. Indeed, non-technical factors should be given due consideration in all housing schemes if the problem of unacceptability is to be avoided. It is a welcome development to note that in a recently published Ghana National Housing Plan of

Action, emphasis has been placed on the inter-disciplinary approach and utilisation of R & D scientific information available. Skilled artisan and professional capabilities are also to be strengthened to play an important role in the national housing delivery programme. The National Housing Policy is also to take cognisance of local level of technological development, economical strength, social and cultural heritage and of institutional view points. The whole problem of national housing policy formulation strategies should be flexible and to involve a lot of research and financial inputs to ensure that desired goals are achieved for the majority, so that most of Ghanaians could be decently housed by the year 2000.

Indoor climatic studies have been given some attention at the Building and Road Research Institute and the results of these studies have to be drawn on during design to achieve maximum indoor comfort.

For example, the Institute has established the superiority of earth buildings in terms of indoor climate in the hot season over sand-cement and concrete buildings (BRRI, unpublished data).

7.5 PERFORMANCE OF LATERITIC SOIL-CEMENT BUILDINGS IN GHANA

The performance of the soil-cement buildings ranges from good to very poor. The most important factor is the attitude of the tenants. Those who were conscious of the need for periodic patching of defects on the walls, painting and proper drainage around the buildings do have decent and habitable buildings for long periods. Those who have ignored all aspects of maintenance activities have the foundations of their buildings exposed through erosion and/or walling block work partially collapsed and the buildings are in very deplorable conditions. It is important that periodic maintenance works should form part of the duties of those occupying such buildings. Apparently, the service life of such buildings would depend upon the degree to which attention is paid to maintenance works on the buildings. This is true of all the earth-based buildings including brick, sand-cement and concrete buildings.

7.6 PERFORMANCE OF NON-STABILISED EARTH BUILDINGS IN GHANA

As indicated earlier, one method of evaluating the performance of earth buildings is to carry out inspection of the poor, moderate and good buildings and define their age, construction technology, sources of the material, climatic and drainage environment and through analysis of this data suitable, border line and poor materials (soils) for the given walling technology for the environment can be established.

This study was started in the moist sub-humid climatic zone and some of the results obtained are discussed.

Wattle and daub, Atakpame and adobe buildings were inspected in over seven (7) typical settlements of over 5,000 people. The geotechnical properties of the the soils, some taken from the walls and some from the natural sources are summarised. The age of the buildings are also given and comments related to their rating in terms of performance indicated. This procedure was followed in studying the performance of earth buildings in all the four climatic zones. Information obtained through this study were used for preliminary selection of various genetic and textural lateritic soil types for laboratory studies and for the construction of exposure walls for assessment of performance under field conditions before experimental demonstration building construction were started.

7.7 PERFORMANCE OF TRADITIONAL RURAL BUILDINGS

The traditional walling materials and technologies in rural Ghana are wattle and daub, Atakpame, Adobe and laterite stone. Rammed laterite earth technology was tried in the past but difficulties associated with the manufacture of moulds and other construction problems led to its abandonment. However, with more skilled carpenters and masons now available this walling technology can be revived. This project has as one of its objectives the need to revive and popularise rammed earth walling in the rural earth housing construction.

7.7.1 Wattle and daub building

The distant photograph views of wattle and daub building are taken. A close up view showing the framework of vertical bush sticks and horizontal bamboo pieces illustrate the type of failures characteristic of this walling type are also shown.

7.7.2 Atakpame building

Atakpame walling as stated earlier is more tideous and perhaps time consuming and does not require timber or bush sticks reinforcement. The nature of Atakpame house is illustrated elsewhere in the report together with close up views. It has been established that the main failure pattern is vertical shear cracks some of which extend from the top of the wall to the foundation. The major design defect is lack of provision of aprons; it is therefore easy to experience the erosion of foundations which may lead to the collapse of the buildings.

7.7.3 Adobe building

Typical adobe buildings have been photographed. By comparison, it was noted that there is a vast difference between the adobe and Atakpame houses built at the same time. In some situations builders have combined the Atakpame and Adobe block walls to give habitable houses. The main failure of these walls is the wearing off of the plaster during the chemical deterioration of the unstabilized walls and also to exposure of the walls to driving rainstorms. There are cases where rural builders have overcome these problems and produced good adobe walls but still the apron is not provided.

Some attempts have been made at village and rural levels to produce and build adobe walls. The production of good quality adobe blocks is one of the main objectives handled in this project execution. Moulding of these blocks in wood moulds at conditions not properly defined can lead later to the failure of the walls built with them.

7.7.4 Laterite stone building

Housing construction using laterite stone is a common feature where these materials are abundant. These materials are very common in all except the humid climatic zone. Dwelling houses and church buildings have been constructed in the moist sub-humid climatic zone. The predominant use of this material for walling using cement or clay mortar is in the arid and dry sub-humid zones where they are used to build simple traditional thatch roofed rural buildings; the technology is however, very poor. Studies in other climatic zones have revealed interesting results, these will be discussed when defining criteria for materials selection.

7.8 FIELD DATA COLLECTION CHART ON PERFORMANCE OF EXISTING EARTH BUILDINGS IN GHANA

The main factors on which data had been collected are as follows:

a. Climatic zone

b. Type of earth building

c. Age of building

d. Sample from existing wall of good performance

e. Sample from existing wall of border line performance

f. Sample from existing wall of poor performance

g. Source of the material used in the construction.

   (Definition of good, borderline, and poor are based on intensity of vertical cracks in the walls and the degree of surface erosion of clay or cement-sand construction and lime-soil plastering).

h. Name of the village/town

i. Predominant laterite soil type described in pedological terms (groundwater laterite, savannah ochrosol, forest ochrosol, oxysol, where this is possible).

j. Erosion condition near the building

k. Topographical features of the building site (approximate slope)

l. Relationship of buildings to east-west and major wind direction.

m. Relative humidity, temperature, rainfall data where available (minimum/maximum values).

n. Vegetation and whether they constitute wind brakes or not.

o. Economic activity.

A chart for rating the performance of the existing buildings is shown in Table 7.1.

The detailed results of the qualitative field assessment work are summarised in the attached self-explanatory tables and figures.

The results of the qualitative evaluation exercise carried out on the lateritic buildings constructed with the main technologies namely: lateritic stone boulder construction; wattle and daub walling; Atakpame (cob-swish) construction; adobe block construction; and rammed earth (pise) walling have revealed that pratically the rural communities have not benefitted in any way from the vast scientific, technological and professional knowledge that are expended on the urban high technology materials housing delivery strategies that we see in the main cities of Ghana. For the purpose of clarity we are going to deal with failure mechanisms and patterns associated with the rural housing construction technology in relation to the materials used and the climatic environment in which the buildings have been built.

7.9 FOUNDATION FAILURES

The field studies have shown that virtually no standard foundation engineering code of practice have been involved and widely publicised for the benefit of the rural housing construction communities. Indeed, some of the buildings do not have foundations at all. In many cases where the foundations have been provided they have not been properly designed nor have they been located below the zone of seasonal temperature and moisture variations which induce alternate swelling and shrinkage of the soil below the shallow foundations, and this induces cracks in walls constructed with all the technologies enumerated earlier. Erosion of soil around foundations and on the compounds of villages and smaller settlements have greatly undermined the buildings, and in most cases, deep gulleys whose repair and maintenance cost implications in any exercise to rehabilitate rural settlements is quite frightening. Foundation erosion and under-scoring therefore deserve special attention by specialists now that a scheme for rehabilitation and upgrading of rural settlements appeared to be prime candidate for immediate action to reverse the rapid decline (through collapse, especially during the rainy seasons) of already very limited rural housing stock where the occupany ratio appears not below 9-10. Contribution towards improving the design and construction of adequate foundations for earth buildings have been comprehensively discussed elsewhere (e.g. Hammond, 1984; Gidigasu, 1977, 1985, 1987, 1988; Gidigasu and Andoh, 1980, 1987; Gidigasu and Appeagyei, 1984). Technical contributions that have resulted from this study towards ensuring good foundation practice for rural housing in Ghana have also been discussed in Chapter 15 of the report.

7.10 FAILURE PATTERNS OF EARTH WALLS IN GHANA

The commonest problem in rural earth walling technologies identified with all construction methods are as follows:

(a) Vertical and horizontal cracking of walls placed on poor foundations. These cracks appear to be due mainly to shear failure and/or shrinkage of the more fine-grained materials. The study has shown that the worst walling technology in terms of proness to the above failure are the Atakpame walls, followed by adobe walls placed on poor foundations.

(b) The next type of wall failure is erosion generally at the base of the walls, and this also leads to premature failure of the walls. This problem of surface erosion is common to all the walling technologies even though the poor construction technologies may also contribute. The wattle and daub walling construction appears to be a developed stage of Atakpame walling because the bush sticks as well as the bamboo reinforcement have been responsible for sustaining some of the buildings inspected for over 60 years. The Project Team believes that improvement upon the method of wattle and daub walling may prove more resistant to such natural disasters as earthquakes, driving rainstorm, etc. Indeed, it would seem that improved wattle and daub technologies with proper finishes would be a better method of wall construction in the Greater-Accra area which is a zone prone to earthquake tremors.

Another yet important wall failures are caused by shear degradation, especially of the adobe walls and mortars. Contributions to this problem have also been made in Chapter 15.

7.11 FAILURE OF EARTH BUILDING PROTECTION METHODS (PLASTERING)

Wall plastering is not a common phenomenon in the rural housing communities, however, most of the walls that have been plastered with clay and stabilised materials and painted with bituminous materials have generally performed satisfactorily. The problem generally arises when attempts are made to use soil-cement mortars (of considerably higher strength than the walling material) to protect earth walls. When this soil-cement or soil-lime plasters are subjected to alternate wetting and drying, cracks developed as first signs, rain waters enter these cracks, the cracks expand and in due course, the entire plaster peels off enbloc.

Wall protection in our tropical environment is a major problem and major contributions have been made in this area in India (Matur, undated) and also in Ghana over 20 years ago (e.g. Bawa and Hornsby-Odoi, 1965). The proposal made by Bawa and Hornsby-Odoi has proved very successful in protecting scientifically designed and constructed earth buildings in Ghana. A brief description of this solution has also been given in Chapter 15.

7.12 FAILURE OF RURAL BUILDING ROOFS

Though considerable contributions are available in literature on the appropriate ways of roofing earth buildings for protection against premature failures, the information has not been made available by the scientific community to the rural poor. Having said that, I hasten to add that two key contributory factors to premature roof failures especially in high-speed driving windstorm prone areas have been ignored. It has been assumed that the concept of the life expectancy of roofing sheets does not exist. Decay of roofing timber components coupled with corrosion of both the wire nails and the roofing sheets themselves creates situations where the roofs are easily ripped off. Another important contributory factor is lack of wind-breaks. With excessive felling of trees around settlements and failure to replace them with new ones to serve the purpose of wind-break, we should expect the present rate of occurrence of rainstorms blowing off roofs. Some discussion on the issue has also been given in Chapter 15. All said and done, the results of field performance evaluation of our rural earth buildings indicate that there is the need to introduce scientific rural housing strategies, and available research findings as well as the capabilities available in the country for the urban strong, durable, and indoor comfortable housing delivery process should be made available through committed national institutional framework to ensure decent rural housing delivery policy.

8.0 STUDIES TO RECONFIRM THE PROPERTIES OF THE DOMINANT LATERITIC MATERIALS IN GHANA

8.1 INTRODUCTION

The first attempt to develop an engineering soil map for Ghana was made by Arulanandan and Bhatia (1960). The basis for grouping Ghanaian soils were geology, geomorphological features, climate, topography and drainage conditions, predominant soil forming processes, soil profile characteristics (morphology), texture (lithology) and the predominant clay mineralogy. Ranges of natural moisture content, insitu dry density, specific gravity, gravel content; Atterberg limits, base exchange capacities as well as bearing strength properties expressed in terms of 48-hour soaked CBR values were given for the seven (7) dominant soil groups identified and mapped. Variations of these properties with depth were also given for typical profiles identified (Arulanandan and Bhatia, 1960). The main limitation of this contribution is that it did not consider the textural differences of the materials within each soil groups and the very wide ranges of geotechnical properties reported made the practical application of this soil map for construction purposes very difficult. Nevertheless, it stands out as a major pioneering contribution to engineering soil mapping and geotechnical characterisation of Ghanaian soils for engineering purposes.

8.2 PEDOLOGIC GEOTECHNICAL STUDIES

The oldest soil map developed for Ghana is the pedological soil map. In all, 23 major soil groups were identified. Detailed information on the modes of formation, morphological features, typical profile features, particle size distribution, physico-chemical properties (pH, cation exchange capacity, exchangeable ions, air-dry moisture content, organic matter content), as well as other relevant information concerning soil structure and fabric, degree of aggregation, cementation, hydration, desiccation, lithology and predominant clay minerals of typical soil systems are given in various pedological soil reports of the Soil Research Institute (Ahn, 1970; Bampo-Addo et al., 1968; Brammer, 1962; Obeng, 1970). A simplified pedological soil map for Ghana was developed (Fig. 8.1). Note that considerations of inter-relationships between local geology, climate, topography and drainage conditions on the one hand and the distribution of the dominant soil forming processes on the other have contributed significantly to the identification of the nature of end products of the weathering and form significant pointers in the definition, identification and mapping of the important pedological soil systems in Ghana for potential engineering application.

8.2.1 Methods of sampling soil for mapping

Identification of the soil deposits reported in the map was carried out on the basis of studies of comprehensive pedological sub-soil reports of the Soil Research Institute (CSIR) and other scientific papers dealing with the genesis of some Ghanaian soil systems (e.g. Cooper, 1936; Hamilton, 1955, 1964; Stephen, 1953; Ahn, 1970; Brammer, 1962).

In profile studies special attention is paid to variations in appearances in the vertical direction of exposed materials in trial pits, road cuttings, or quarries as well as identification of materials sampled from auger boreholes, usually to depths of about 3m. Particular attention was also paid to the importance of topographic site, nature of the horizons, texture, colour, structure, degree of desiccation, and general morphology including the presence or absence of stoneline, and gravel beds, etc. A procedure for sampling and field identification of soil materials in relation to topography and profile features has been discussed in detail by Ahn (1970) and Gidigasu (1976). The significance of the soil forming factors in the development of general characteristics of the dominant soil groups including the profile features, clay mineralogy as well as the geotechnical implications of the interrelationships between these factors and soil properties have been reviewed in detail elsewhere (Gidigasu, 1971, 1972, 1976, 1980; Gidigasu and Kuma, 1987).

8.3 PREVIOUS GEOTECHNICAL STUDIES OF LATERITIC MATERIALS IN GHANA

Between 1964 and 1989, there have been comprehensive and detailed geotechnical studies of lateritic materials of Ghana and the results have appeared in over 80 journals and conference publications and technical reports (e.g. Gidigasu, 1971, 1972, 1974, 1975, 1976, 1980, 1989; de Graft-Johnson et al., 1969, 1972; USAID, 1971; Gidigasu and Kuma, 1987, etc.) The basic grouping of the lateritic soils have been based upon the consideration of the pedological information available, and the evaluation of specific environmental factors that shaped the genetic characteristics such as their textural and compositional factors. Generalised characterisation of the lateritic soils of

Ghana mainly from textural and morphological view points have been proposed and found to be very useful (e.g. Gidigasu, 1971, 1972). The geotechnical and physico-chemical properties of lateritic soils and rocks identified in Ghana have also been comprehensively discussed elsewhere (e.g. Gidigasu, 1971, 1972, 1976, 1980; de Graft-Johnson, Bhatia and Yeboa, 1972; de Graft-Johnson, Bhatia and Hammond, 1972; Gidigasu and Yeboa, 1972; Gidigasu and Kuma, 1987). The review of literature on the characteristics of lateritic soils of Ghana for potential use as raw or stabilized walling block-making materials was also recently published (Gidigasu, 1989). For example, the chemical characteristics of lateritic soils was found to be very pertinent to stabilisation problems and laterite stone development is associated with well-drained sites. The chemical implications of the processes of lateritisation, namely the leaching away of silica (SiO_2) and enrichment of sesquioxides (Al_2O_3 or Fe_2O_3) either together or separately to form the aluminous and ferruginous lateritic materials have also been discussed elsewhere (e.g. Cooper, 1936; Hamilton, 1955). The most important contribution has been the identification and grouping of lateritic materials of Ghana from the view points of texture, and major genetic characteristics of importance to geotechnology either in the field of highway, or foundation engineering or from earth building construction view point (Fig. 8.2). A compact and elaborate geotechnical grouping of lateritic materials of Ghana has been given elsewhere (Gidigasu, 1976). One aspect of the current research programme is to confirm the results of all the earlier geotechnical studies on lateritic materials of Ghana and to identify the areas of relevance to earth building construction in Ghana. The relevant supplementary studies were undertaken on lateritic materials in the four main climatic zones of Ghana. Specific studies on soils used for demonstration buildings construction were also undertaken.

8.4 SCHEDULES OF PROJECT EXECUTION

The project had three years of execution period. Due to delay in receiving the first payment of the "Centre Grant" it was not possible to secure the project vehicle in time to start field material sampling and transportation to the laboratory for preliminary geotechnical characterisation to be followed by trial production of the materials in the temporary materials laboratory (shed) at Fumesua after which exposure walls would be constructed. The procedure of materials identification, pitting and sampling had to be established. Table 8.1 gives the proposed schedule of distribution of pitting, soil sampling and preliminary studies. The Table has attempted to highlight the key factors that control the soil forming processes, and significant compositional and genetic features that would enable the separation of the soil types into groups to which they are pedologically known. The key genetic characteristics of the four (4) climatic zones have been indicated. Following previous experiences (e.g. Ahn, 1970) actual field studies such as pitting, profile characterisation and material sampling from the three (3) main horizons for laboratory and preliminary examination and characterisation were decided on. Due to earlier transportation problems and the known heterogeneity of the forest ochrosols necessitating the choice of rather large number of pitting, profile studies and soil sampling programme, the moist sub-humid zone in which Kumasi is located was chosen for the first phase of the project execution. The idea has been to carry out as many pitting, profile studies and geotechnical characterisation as possible at a number of sites and then select one or two pits of special interest in terms of their abundant occurrence over particular parent rock types for carrying out walling material production studies in more detail. The location of pits in the four climatic zones are shown in Fig. 8.3. For example, the sites for moist sub-humid zone include Kumasi, Sunyani, Nkawkaw, Dunkwa, Bibiani, Bunso and Takoradi. The flow charts for the laboratory characterisation of the raw and local lime stabilised lateritic soils have been discussed elsewhere in the report.

8.5 CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES

In order to reach a practical and economic solution to engineering problems some method of identifying soils and grouping them into classes, each displaying similar physical properties and similar general behaviour characteristics, was necessary. Various systems have been developed for classifying soils for engineering purposes. Some are based on modifications of known systems such as those used in agriculture, geology or pedology, which were developed to describe and catalogue soils according to a particular non-engineering property or to their mode of formation or deposition. The first known attempt to classify soils for engineering purposes was based on the experience and soil-testing procedures developed by the agricultural soil sciences. Most of these classification systems were based on the relative contents of the three grain-size fractions of sand, silt and clay; while later classifications used the entire grain-size curve. Probably, the first departure from the grain-size analysis as the exclusive basis for soil classification was made by Atterberg in 1911 who proposed the use of plasticity in addition to the particle-size distribution for the classification of soils for agricultural purposes.

8.5.1 Particle-size classification

Soils consist of mineral particles which cover a wide range of sizes. It has been found useful to assign names to describe particles which lie between certain size limits, such as boulders, gravels, sands, silts and clays. These names are convenient to use and give more information than does a mere statement that the particles lie between certain size limits. Many systems for the particle-size limits of the various soil components have been proposed and use. All of the particle-size limit schemes are arbitrary since no distinct divisions can be made between the members of a continuous series. The originators of the various systems were influenced by many factors when making their selections. These include the field of study such as agriculture, engineering, geology, etc., the convenience of investigation, the methods and apparatus available for analysis, the ease with which data could be presented, the convenience for statistical analysis, the previous work done and the systems used, etc. (Roderick, 1972).

Some of the investigators tried to place the limits so that they would correspond with the various properties of the soil components; many were more interested in easily and conveniently obtained and presenting data.

8.5.2 Textural soil classification systems

The principle of classifying soils purely on the basis of their grain-size distribution dates back to the time when it was not yet realised that the physical properties of fine-grained soils, with a similar particle-size distribution, can be widely different. The simplicity of textural soil classification systems and the fact that they can be applied with little experience, are the main reasons why they are still widely used. Original textural classifications were based on the relative percentages of the sand, silt and clay-size fractions. They are facilitated by plotting these three fractions on a triangular chart (Fig. 8.4). The difficulty of triangle classifications, however, lies in the fact that those physical characteristics of fine-grained soils which are of interest to the engineer are often not reflected by the three fractions alone. However, textural classifications based on the entire range of particle size may be useful for cohesionless soils of the same geologic origin.

8.5.3 Textural and plasticity soil classification systems

To assist in identification, Atterberg (1911) proposed the use of plasticity tests as well as a dry strength concept. This classification has emphasized pertinent physical characteristics whose differentiation is not possible by using particle-size distribution alone. The plasticity tests were standardized by

Casagrande (1932) for the identification and classification of fine-grained engineering soils. This was based on the relationship between the liquid limit and the plasticity index for different genetic soil types from different parts of the world which were examined by Casagrande (Fig. 8.5). The position of the various soils on the chart has emphasized the extreme value of the plasticity concept. For example, bentonite and kaolinitic clay soils may plot at the same point on the textural triangular chart, but their positions may be widely different on the plasticity chart.

On the basis of this study, Casagrande (1948) proposed a plasticity classification chart for soil fines (Fig. 8.5) with the so-called A-line which represents an empirical boundary between typical inorganic clays (generally above the A-line) and the plastic soils containing organic colloids (which are below it). "It goes through the point on the base line having a liquid limit of 20, and through the point with a liquid limit of 50 and a plasticity index of 22, and its equation is: plasticity index = 0.73 x (liquid limit - 20") (Casagrande, 1948).

8.5.4 Unified soil classification system as applied to natural temperate zone soils

The Unified Soil Classification System (which is the most versatile and universally accepted of all existing soil classification systems) is significant attempt to classify almost all natural soil into fifteen groups on the basis of their texture and plasticity characteristics, the processes of definition and classification are given in Table 8.2.

From knowledge of the particle-size distribution and plasticity characteristics, it has generally been possible to infer the engineering properties and behaviour based upon characteristics of other soils classified similarly. Wagner (1957) has shown that there is a good correlation between four important properties of the fifteen soil groups and their desirability for use in rolled earthdams, canal sections, foundations and roadways.

8.5.5 Textural classification of normal lateritic materials

The relationships between soil texture and parent-rock types are of particular significance in the textural classification of residual laterite soils because they form a broadly based basis upon which a preliminary textural grouping of laterite soils could be made. Indeed, in the textural classification of residual fine-grained soils, the relationship to parent-rock type, weathering conditions, degree of lateritization and geologic origin are crucial factors to be considered (Gidigasu, 1971a, 1972). It is necessary, in the first instance, to identify the group of laterite soils that have been formed by similar pedogenic factors before proceeding to undertake particle-size analysis and textural classification. The tendency is for arenaceous parent-rocks to produce sandy soils and for the argillaceous parent-rocks to produce silty clay soils. The influence of the parent-rock type on the textural characteristics of lateritic materials have been discussed elsewhere (e.g. Gidigasu, 1971).

Apparently, one of the main characteristics of lateritic materials is the high percentage content of fines (silt and clay fractions) (Ackroyd, 1967; Gidigasu, 1972); therefore it appears that these soils may not be loosely defined as gravel-sand-clays as is currently done (e.g. O'Reilly, 1958). On the basis of the gravel, sand and fine fractions (passing No.200 B.S. sieve) it may be possible to group laterite gravels and gravelly soils into six textural classes which appear to have similar geotechnical characteristics (Fig. 8.6). The significance of this triangular chart is only obvious, however, when it is applied to the same genetic soil group (Gidigasu, 1969).

The features of the Unified Soil Classification which make it desirable and advantageous for categorizing soils according to their engineering properties have been discussed by Wagner (1957) as follows:

(a) The system is related to the physical properties inherent in the soil and not to a particular use. Thus, it may be used for all types of engineering problems involving soils.

(b) The system is based on soil behaviour which, in turn, reflect the physical properties.

(c) The system recognizes that soil behaviour is a function of the amounts and the distribution of the basic constituents common to all soils; particle-size fractions, moisture, and other substances such as organic matter, gases, and minerals which coat the grains or act as cementing agents.

(d) The system established fifteen soil groups each of which have distinct engineering properties.

(e) The system provides two methods for determining the amount and types of the basic components in the soil; a simple visual and manual method and a laboratory method which uses standard laboratory index tests (e.g. British Standards Institution, 1975). The maximum size, amount, distribution and shape of the particles in the coarse-grained soil compounds are estimated by visual examination or are accurately determined by a grading test; and the type of fine-grained component is determined by estimating the plasticity using the field identification procedures for fine-grained soils or fractions (dry strength, reaction to shaking, toughness, etc.). Laboratory tests are then carried out to accurately identify the material using Casagrande's plasticity chart.

(f) The system uses names and symbols to distinguish between the typical and boundary soil groups.

(g) The system provides for the classification and description of soils both for construction purposes and for use in place as a foundation.

Procedures for classifying soils according to the Unified Soil Classification system are shown in Fig. 8.7. The characteristics of the fifteen soil groups of the Unified Soil Classification system are shown in Table 8.3. A major weakness of all textural-plasticity classification systems is that they deal with remoulded soils and tell little or nothing of the structure of the soil insitu. This weakness can be alleviated to some extent by giving all available information, geologic, pedologic, etc. to establish aerial extent, occurrence, and in-place conditions of the different types of soil strata in a foundation or proposed material source.

8.6 GENETIC CHARACTERISATION OF LATERITIC MATERIALS

Those who are conversant with the characterization of temperate zone sediments containing mainly kaolinite and illite minerals might not see the need to discuss weathering processes. However, the need for information on the formation and genetic characteristics of these naturally occurring gravelly soils will be appreciated later in the paper. For example, tropical gravels are generally heterogeneous, morphologically, texturally, chemically, physico-chemically as well as mineralogically and as these genetic and compositional factors considerably influence geotechnical properties and engineering behaviour we need to draw on this data to evolve meaningful standards for highway geotechnics for tropical environments. The importance of geology and pedology as well as the need to differentiate one material from the other from various view points have been summarized by three noted international specialists. According to Skempton (1953) in soil mechanics one is dealing the geological materials in a natural geological environment, and to neglect this fact is to run the risk of a short-sighted approach which may, in the extreme cases, be nothing less than disastrous, but the debt of geologists to soil mechanics is also becoming considerable in practice, since the methods of soil mechanics apply qualitative results to engineering geology problems.

Wooltorton (1955) stated that engineering pedology is the science of investigating engineering soil problems, making use of all the natural laws known to be operative under the particular and specific conditions prevailing. Engineering pedology begins with the knowledge of rocks (parent materials) and weathering conditions and processes from which it deduces logically the nature of the end-products, especially the morphology, lithology (texture), chemistry and mineralogy. In pedology is to be found an understanding of the secrets of soil properties such as those of cohesion, of their resistance to stress, their moisture relationships, their reaction to the various kinds of additives incorporated for the purpose of moisture and strength stabilisation. Kubiena (1948) asserted: "Show me your (classification) system and I will tell you how far you have come in the perceptions of your research problems".

Recent developments in geotechnical engineering practice (e.g. Mitchell, 1976) have revealed that there are major limitations associated with even the very popular Unified Soil Classification system. This has caused the development of numeral regional and national soil soil classification systems, especially for tropical residual and unusual soils. Among the many classification systems and development trends reported in literature are:

(a) The plasticity and colloidal activity index soil classification system (e.g. Vargas, 1988).

(b) Developments in the recognition, characterisation, testing, identification and classification of tropical residual soils (e.g. Brand and Philipson, 1985).

(c) Application of degrees of chemical weathering in the identification and characterisation of tropical soils (e.g. Little, 1967; Gidigasu, 1974; Gidigasu and Kuma, 1987; Sueoka and Lee, 1988).

(d) Field recognition, description and identification of tropical residual soils using pedological data (e.g. Gidigasu, 1988.

(e) Morphological characterisation and identification of tropical residual soils (e.g. Brand and Philipson, 1985; Cooke and Neville, 1988).

(f) Fabric (micro structure) and pore size as indicators for the engineering characterisation of tropical soils (e.g. Lohnes et al, 1973; Irfan, 1988; Tuncer, 1988).

(g) Mineralogical composition in the identification of tropical residual soils (e.g. Wesley, 1988).

(h) Chemical and mineralogical composition as indices for classifying tropical residual soils for engineering purposes (e.g. Shellman, 1979; Ingles and Metcalf, 1972).

Coupled with the above developments some soils have been found to be so different genetically, particularly due to the presence of certain clay minerals, or peculiar fabric, or presence of salts that they do not render themselves amenable to the standard laboratory and field identification and classification tests and procedures. Some of these materials include dispersive soils (e.g. Emerson, 1957; Sherard et al, 1976), erosive soils (e.g. Holtz and Gibbs, 1967); structurally sensitive soils (shrinkable soils) (e.g. Tuncer, 1989 and Lambe, 1960; Gidigasu, 1971; Danson, 1972, extremely variable in terms of moisture content and strength properties (e.g. Hirashima, 1948) or due to some compositional factors the strength properties are variable (e.g. Salasetal, 1973) as well as collapsible soils (e.g Dudley, 1970; Reginnato et al, 1973). Methods for identifying these unstable and sensitive soils have been discussed in detail in the literature cited. The classification charts, tables and behaviour during the drying process, their behaviour in relation to relative humidities, heating temperature versus loss in weight relations, variabilities of moisture with depth, and effect of salts on the collapse potential and strength are summarised in Figs. 8.8 to 8.18. For the purpose of further discussions the study was confined to the stable lateritic materials that have been identified using Table 8.4. The geotechnical characterisation flow chart used is given in Fig. 8.19, while summary of significant properties and useful testing procedures are summarized in Table 8.5. Two main soil types from the Kumasi area were used for detailed studies for the production of adobe blocks and rammed earth wall as well as local lime stabilisation for block production. They are reddish fine-grained soils, the SANTASE SOIL and the micaceous sandy loam, FUMESUA SOIL. They are the commonest soils formed in the moist sub-humid zone lateritic and residual materials. The laboratory tests all conform to the British Standards Procedures (B.S. 1377, 1975), except that we used air-drying instead of oven-drying for the identification and classification tests. This is based on established fact of the undesirable effects that the oven-drying do have on some of the lateritic soils, and Ghanaian lateritic soils are not exception (e.g. Gidigasu and Yeboa, 1972).

The particle size distribution, plasticity classification, and textural classification as well as compaction characteristics of typical lateritic loamy clay (decomposed phyllites) are also given in Figs. 8.20 to 8.30. The effect of depth of sample, compaction degree on the one hand and the bearing strength (CBR), as well as swell and uniaxial compressive strength are also summarized in Fig. 8.31 to 8.36.

Detailed discussion of the results presented as charts, tables and figures are self-explanatory, reference will be made to them in more detail when investigating them for the production of adobe blocks, rammed earth wall and lime stabilised block production.

9.0 CHARACTERISATION OF LATERITIC MATERIALS IN GHANA FOR THE PRODUCTION OF ADOBE BLOCKS AND RAMMED EARTH WALLS

In designing earth buildings the specialist should know the relevant significant soil properties such as the strength, durability, volume stability, permeability and moisture absorption. The construction engineer or architect generally has to make use of variable soil, gravel, or rock materials to construct the buildings. He must be properly equipped to provide suitable, reliable, acceptable and affordable buildings that meet the needs of the beneficiary.

9.1 STRENGTH

Strength is a critical parameter in the stability of earthen materials. Tests used to determine the strength of soils as a construction material can be divided into three groups namely, shear, bearing and penetration. Shear tests are usually made on comparatively small samples in the laboratory and thus only determine effectively the strength properties at a point in the soil mass. Some shear tests can also be used to determine the modulus of deformation for use in theories of stress distribution in an assumed earth wall thickness requiring a value of the modulus of elasticity. Bearing tests are in a sense loading tests made in the field on the surface of the soil mass. The results are therefore affected by variations in soil properties within the volume of the soil stressed, and give an overall measurement of the strength of a part of the soil mass.

Penetration tests are made either in the field or in the laboratory and like shear tests, only determine effectively the strength properties at a point in the soil mass.

It is to be noted that adequate strength is a basic requirement for the stability of earth buildings.

9.2 DURABILITY

In common with all other construction materials, resistance to the processes of weathering, erosion, and chemical degradation is a very desirable condition. This may be termed durability. A wide range of durability is found in natural rocks and soils and the upgrading of those with poor durability is often desirable. Poor durability can be a problem both in natural and stabilised soils and is chiefly a surface problem. Low durability earthen construction materials is reflected in high maintenance costs rather than in major structural failures, although structural failures are known to occur in special cases.

In some natural soils, poor water resistance is associated with dispersive and erodible soils. In stabilised soils, poor durability can result from aspects such as inferior mix design, a wrong choice of stabilizer, insufficient stabilizer, or inadequate chemical or water resistance to weathering.

A number of tests for assessing the durability of soils and stabilized soils for building construction have been proposed but most of them are deficient. For example, weathering tests have not been sufficiently developed to enable us define abrasive resistance, and tests of water resistance are generally qualitative rather than quantitative. Because of the lack of universally standardised test procedures, durability is one of the most difficult earthen material evaluation problems the building designer must face. A common solution is to overdesign; this can be neither economic nor even technically sound.

9.3 VOLUME STABILITY

Many clayey soils swell or shrink with changes in their moisture contents. These volume changes if uncontrolled, may rapidly disrupt wall surfaces, causing cracking of the walls; this leads to economic loss. The swell and shrinkage may be caused mainly by changes in the water contents of the soil, and can be wholly overcome by preventing these changes. Various methods of controlling moisture variations and soil volume changes have been proposed in recent years in earth building construction technology with various degrees of success particularly when dealing with clayey soils (e.g. Okine, 1970). Volume stability may be ensured either directly through the control of allowable volumetric changes or indirectly through specifications of allowable limits of some soil index properties such as fines content or Atterberg limits (e.g. Houben et al., 1989). The magnitude of volume changes caused by moisture changes depends essentially on the mineralogy of the soil. For example, soils containing expansive clay minerals such as montmorillonite should generally be avoided while kaolinitic soils with low swelling properties should be preferred. The control of the potential volume changes is related to the stable moisture content associated with the relative humidity of an environment. For example, in wet areas stricter controls should be placed on the fines content and on the plasticity limits while in drier areas the specification limits may be relaxed.

9.4 PERMEABILITY

Permeability presents engineering problems in earth building construction especially as regards the capacity of the soil to absorb water. Low permeabilities are usually associated with soils of high clay content, especially when some soil salinity is present. Desiccation of a cracking clay leads to high initial permeability when re-wet.

9.5 PREDICTION OF LONG-TERM STABILITY OF SOIL BASED BUILDINGS

It has been established (e.g. Gidigasu, 1987) that the stability of soil based building materials can be partially predicted through laboratory and field studies. Some of the important laboratory tests include the weeathering and crushing strength tests on manufactured blocks cured after specific periods. These tests have received a lot of attention and it has been established that when appropriate moulding moisture, density and pressure conditions are selected the dry crushing strength can be fairly high. Indeed, the wet strength can also be appreciably high and earth wall designs can be based apparently on the crushing strength of the blocks alone. But when we start considering the behaviour of the building walls on long term basis the key soil properties are resistant to cracking, chemical degradation and weathering as well as decline in durability.

Durability test of various kinds have been evolved; some directly and others indirectly. For example, the linear or bar shrinkage test is meant to assess the extent to which the wall, if not properly protected, can shrink. Shrinkage may cause a lot of cracks in earth walls. Water enters these cracks, gets to the wall itself and triggers off pronounced processes of chemical weathering and degradation of the wall. In trying to prevent the long-term degradation of earth walls, sand, lime, cement, bitumen or straw stabilisation have been introduced. These stabilisers act to control the degree of shrinkage and secondly, they serve as a protection against the adverse effect of water.

The results of the study under this project have amply confirmed that laboratory tests alone have many limitations. It is, therefore, desirable to undertake field studies on the performance of different types of earth walls in the various climatic conditions. The project team also studied the exposure walls constructed at Fumesua of adobe, rammed earth and lateritic stone cut blocks; they will still be observed for a long time. These walls have undergone a few dry, and rainy season periods. Studies on some walls that have been exposed for many years when the building roofs were ripped off by rainstorms have also been examined. For example, some walls have been exposed to rainstorm for 5 to 10 years and are still standing. This seems to suggest that earth walls do undergo some processes of desiccation resulting in the development of new micro-structures of the walling materials making them very resistant to the adverse effects of the alternate drying and soaking from the driving rain water. A literature search including experiences gathered at the Building Research Establishment (Coad, 1979; Lunt, 1980) and considerable field tests carried out in Ghana (e.g. Sperling, 1962; Bawa and Hornsby-Odoi, 1965; Gidigasu, 1965; Coad, 1979; Lunt, 1980; Okine, 1970) indicate that even emersion of blocks in water, water jets test of blocks for some period are unable to provide sufficient criteria for separating the good borderline and poor materials selection criteria and for the prediction of the long term stability of earth walls under field climatic conditions.

It does appear that the performance of earth walls in the various climatic conditions would form the basis of defining optimum criteria particularly for materials selection for the suitable rammed earth and the lime stabilised blocks walls.

As regards the problems of earth walls protection by plastering, using various materials and construction technologies against weathering due to effects of water, the literature survey and field studies have shown that environmental factors such as relative humidity, wind direction, rainfall intensity, temperature etc. are relevant parameters to be considered by the designers to ensure acceptable indoor climate for human habitation. During the end of project seminar the recommendations which will form the basis for evolving the materials acceptance criteria, standards, specifications and Codes of Practice would be discussed. In particular selection conditions definition and construction technology, protection of the walls, and design aspects in relation to the orientation of the building east-west to ensure acceptable indoor climate will also be discussed. Protection of the foundation as well as the ground around earth buildings against erosion will also be discussed and conclusions drawn to guide earth building construction industry in the West and Central Africa. In the Inception and First Technical Report the process of winning lateritic soils formed in the moist sub-humid climatic zone over phyllite (schist) and over muscovite granite (to form micaceous soil) were discussed. The most important lateritic soil types in the dry sub-humid zone are the well-drained savannah ochrosols formed over igneous and metamorphic rocks and the groundwater lateritic soil formed over shale and mudstone under poor internal drainage conditions.

The soil from the dry sub-humid zone was sampled from Poase Cement and subjected to classification testing and compaction characterisation in the laboratory for the purpose of defining the conditions of moulding the adobe blocks. It was expected that after the construction of the first demonstration building at Kokoben (Kumasi) the definition of moulding adobe block conditions for groundwater lateritic soils in the semi-arid zone as well as for oxysol formed under the humid climatic zone of the south-western part of the country will be better appreciated. A lot of effort has been made to identify the lateritic soils compaction conditions for trial moulding of cylindrical specimens which were subjected to laboratory uniaxial crushing tests after various curing periods and conditions. Since some of the soils could be very clayey, sand stabilisation was also included in this phase of the study. The process involved the blending of the very clayey soils with specific quantities of defined sand, and on the basis of curing and crushing tests the optimum sand content required and the density and moisture of moulding of the adobe blocks were defined.

9.6 LABORATORY PROCEDURES FOR THE CHARACTERISATION OF TYPICAL LATERITIC SOILS

9.6.1 Pitting and taking of soil samples

The pits were dug with pick-axes and mattocks as well as hand augers with the materials sampled at appropriate depths. Soil sampling was carried out to depths of about 3m. The main three horizons of lateritic soil profiles were then defined, namely laterite zone below the humous rick top soil (which extends to a depth of about 1.00m); the mottled horizon (which extends between say 1.00m and 2.10m) and the pallid (saprolitic) horizon (which extends below 3.00m) at the particular site. In dug holes, steps were provided at one side of the pit to facilitate entering for side inspection and coming out of the pit. Colour differences formed the main basis for taking disturbed soil samples into plastic bags, tied to prevent loss of moisture before being conveyed to the laboratory for classification, compaction and uniaxial crushing tests.

9.6.2 Preservation and storage of soil samples

Any soil sample collected is put into a polythene bag, labelled and sealed with sellotape or tied with a string to prevent loss of moisture under field conditions. It is very important to ensure that the polythene bag is not punctured during transportation of the soil samples to the laboratory, otherwise some moisture may be lost through evaporation.

9.6.3 Chemical composition and the particle size distribution

The chemical analyses of the soils from Fumesua and Santase were carried out at the Chemistry Department of the University of

Science and Technology, Kumasi, and the results are summarised in Table 9.1.

The Particle Size Distribution test was carried out using the hydrometer method. Anhydrous sodium carbonate and sodium hexametaphosphate solutions were used for dispersing the fines, before carrying out the test in accordance with procedures stipulated in the British Standards (see Gidigasu, 1980). Air-dried samples were, however, used instead of ovendried ones as stipulated in the B.S. Standard (1377; 1975) (see Gidigasu and Yeboa, 1972). For example, the results of particle size analysis for the specific soils in the trial adobe production studies are given elsewhere in the report. Results for Santase and Fumesua (Kumasi) soils are given in Fig. 9.3 those for Poase Cement are given elsewhere (see Fig. 9.4).

9.6.4 Atterberg limits and linear shrinkage tests

The Atterberg Limits and the Linear Shrinkage tests were carried out under four different conditions.

The first test was carried out on the freshly dug soil; the second condition of test was the freshly dug sample soaked in distilled water for 24 hours; the third condition was the sample oven-dried at a temperature of 105-110 C for 24 hours before test, while the fourth condition was air-drying of the sample at room temperature of about 25 C for 24 hours before the test; the results of Fumesua, Santase, and Poase cement are given in Table 9.2 and Figs. 9.5 and 9.6.

9.6.5 Large mould bar linear shrinkage test

The sample used for this test was prepared exactly as for the liquid limit test. The soil was mixed thoroughly with distilled water to make it near fluid before the liquid limit test. A V-shaped groove was cut in the soil of exactly 2mm wide with the side of the groove sloping at an angle of 60 to the horizontal. If the groove closed after about 5 taps of the dish against the wrist of the hand, the sample moulding moisture condition was just right.

A very thin coating of oil was applied on the inside walls of the wooden mould. This prevented the soil from sticking to the mould during drying. A quantity of the wet soil was placed inside the mould to fill one-third of it. The filled mould was gently tapped on the bench to cause the soil to flow into a smooth layer, thereby removing unwanted air bubbles from the soil paste. Additional wet soil was placed inside the shrinkage mould until it was full. The excess soil was scrapped from top of the mould with a straight edge. The soil bar was then dried. To prevent cracking the sample was dried in stages; the first stage at room tempera-ture of about 25 C for 24 hours and then in the oven at a temperature of 105-110 C to constant weight. The length of the dried soil bar was measured and with known internal length of the mould computation of the bar shrinkage values were carried out (see Appendix 1). Typical test results are given in Fig. 10.5. The results of the Atterberg and shrinkage tests were summarised and are given elsewhere in the report.

9.6.6 Compaction characteristics of the raw soil

The soil from the three zones of the soil profile were mixed in equal proportions into a fairly homogeneous mass before used for testing. The mixed soils sample was air dried at a temperature of 25 C. No quartering was done because the soil was mainly fine-grained. The soil was mixed at different moisture contents, all cured at a constant room temperature of about 20 C overnight to ensure even distribution of moisture in the soil before compaction test was carried out, typical results are given in Fig. 9.7 and Table 9.3.

9.6.7 Compaction test

For the raw soil three levels of compaction were adopted. These are the Modified AASHO, West African (Ghana) and the BS Standard (near Standard Proctor).

In the Modified AASHO Compaction test the compactive effort employed is 4.54kg rammer falling through a height of 45cm on the soil in 5 layers in the CBR mould of 2305cm each layer receiving 55 blows.

The West African Compaction procedure is the same as that of the Modified AASHO except that each layer received 25 blows. In the BS Standard Compaction method the amount of compactive effort was 2.5kg rammer falling through a height of 30cm on the soil sample compacted in 3 layers in the CBR mould of 2305cm each layer receiving 55 blows.

9.6.8 Moisture density relations

The moisture density relationship curves for the micaceous soil were shown in the first technical report. The maximum dry densities range from 1.53mg/m for the BS Standard to 1.67mg/m for the Modified AASHO. The corresponding optimum moisture content range between 17.5% and 14.4%. For the Santase soil, the maximum dry density values were 1.61mg/m for the BS Standard to 1.83mg/m for Modified AASHO. The corresponding optimum moisture contents are 17.8% to 13%.

The test results on raw soils were given in graphical presentations in Fig. 9.8.

9.6.9 Sand stabilisation

In cases of very clayey soil, sand stabilisation was found to be helpful in the manufacture of the adobe blocks. The laboratory sand stabilisation was therefore attempted; the details are reported elsewhere in the report.

9.6.10 Mixing method

Mixing was done by hand. The sand was added to the soil in the following proportions 0%, 5%, 15%, 30%, 50%; thoroughly mixed in a tray before adding water to it. There was the curing of the mixed soil mass for 24 hours before the compaction test was carried out.

9.6.11 Atterberg limits, linear shrinkage and moisture density relationships

The BS Standard (1377/1975) was used for the determination of particle size distribution, Atterberg limits, and compaction tests on sand stabilised soils, except that air drying was adopted throughout. The results obtained were summarised and given elsewhere in the report. The effect of sand stabilisation on the Atterberg limits (Table 9.4) and on compaction curves of the various soils are also given in Fig. 9.9.

9.6.12 Compressive strength test on raw and sand stabilised soils

The whole soil sample was used for the test as was in the case of the compaction test. For the raw soil the moulding condition was the maximum dry density and the optimum moisture content of Standard Proctor Compaction. The sand stabilised soils were also prepared at appropriate maximum dry densities and optimum moisture contents, typical results are given in Table 9.5 and Fig. 9.10.

9.6.13 Moulding of test specimens

Moulding of test specimens was done by static compaction in a 1570cm cylindrical mould. The diameter of the moulded specimen is 100mm and the height is 200mm. Light oil was applied to the inside of the mould before filling it with the soil to make extrusion of the compacted specimen easy and also to avoid shear cracks on the specimen surface during extrusion. The compacted specimen were stored in sealed polythene bags for some 24 hour curing before test. Three specimen were prepared and tested for each preparation condition. The results obtained are summarised and are presented elsewhere in the report.

9.6.14 Surface texture of moulded compacted specimens

The surface texture of the compacted specimens varied from rough to smooth. The raw soil specimens all had rough surfaces; the roughness, however, decreased as the percentage of the additive increased. Generally, the 30% to 50% sand stabilised specimens were quite smooth, visually devoid of any voids while samples containing lower sand contents had varied sizes of surfacial voids on the moulded compacted specimens.

The preliminary laboratory studies revealed that mechanical blending of sand with clayey soils was sometimes helpful to attain optimum grading curves for good adobe blocks manufacture. For example, for most of the soils studied addition of about 30% sand gave the most desirable moulding strength for the adobe blocks produced.

9.7 TRIAL MOULDING OF ADOBE BLOCKS

9.7.1 Taking of Samples from the Pit

A site near Santasi in Kumasi was selected and a pit measuring 2m x 1.54m x 3.5m deep was dug using pick-axe and shovel. Soil samples were collected into polythene bags at depths of 1.0m, 2.0m and 3.0m. Each sample bag weighed about 20kg. The polythene bags were sealed in a manner that would retain the moisture in the soil. Three bags of samples were sampled at each level from the trial pit.

9.7.2 Storage and preservation of soil

The soil samples in the bags were then transported to the Temporary Shed at Fumesua where they were stored until they were ready to be tested or used. Some representative samples from each bag were selected for the determination of natural moisture content and other laboratory tests. The laboratory analysis were carried out by technicians in the BRRI laboratory. Sand stabilisation on the soil was also carried out by the technicians to determine the optimum moisture content and percentage of sand required to be able to achieve the maximum uniaxial strength. When the optimum parameters were achieved, the values were used to mould the blocks.

9.7.3 Preparation of the soil including mixing

Before the trial mouldings were commenced, one bag each of the soil samples from the same depth were thoroughly mixed and its moisture content determined. With the mixer not yet purchased, the mixing was done with a shovel on a wooden platform. After determining the moisture content of the mixture, the amount of water needed to be added to achieve the optimum conditions as given by the laboratory compaction results was added and the mixture mixed thoroughly for over five minutes. Some of the soil mixtures were taken for moisture content determinations. The soil mixture was then covered with plastic bags and wet sacks and allowed to cure for five (5) days before moulding.

9.7.4 Adobe block moulding moisture content and density for the soil

After the determination of the moulding moisture content and the densities which were found to be between 23-28% and 1827 to 1987kg/m respectively, trial adobe blocks were moulded in the TEK BLOCK PRESS. The soil samples were mixed with water to appropriate moisture contents and cured in each case for 5 days using the same procedure as described above.

9.7.5 Moulding of raw adobe blocks

The TEK block machine was used in moulding the blocks. The characteristics of the TEK block machine compared with the CINVARAM Press are given elsewhere in the report.

Initially, the amount of soil to fill the mould was measured but with time it was filled without measuring through the experience gained. Three people were able to mould 150-200 blocks a day when they mixed the soil and moulded the blocks at the same time. But when the soil had already been mixed, the three people could mould between 250-300 blocks a day. The processes of producing the adobe blocks are illustrated elsewhere in the report.

9.7.6 Period of drying under the shed

The moulded blocks were dried under the temporary shed at a temperature of about 25 C for varying number of days ranging from 7 days to 90 days and then dried in the sun at about 25-30 C for 7 days before testing for the uniaxial compressive strength.

9.7.7. Determination of moulding moisture content

Some of the moulded blocks were weighed and some of the soil samples put in the oven at a temperature of 105 C to 110 C for 24 hours to determine the moisture content to enable the moulding dry density to be determined.

9.7.8 Effect of moisture content on the texture of and outside appearance of the blocks

Moulding moisture content had a very significant effect on the texture of the outside appearance of the moulded blocks. It was observed that the blocks moulded with moisture content of the ratio of moulding m/c to the optimum m/c of between 0.8 and 1.2 gave a very smooth and good textural appearance; those with ratios between 1.2 to 2.0 gave appearances which were not so very pleasing to the sight. Some hair cracks could be seen on the block moulded on the wet side of the optimum moisture content.

It was also observed that with moisture contents ratio of 1.6 to 2.0, the moulding became very difficult with the TEK block machine, which showed that the machine was not suitable for making blocks that contain too much water. The ideal moulding water content should be within 5% to 10% wet of the optimum moisture content.

9.8 CHARACTERISATION OF TRIAL MOULDED SOIL BLOCKS

The general characteristics of the moulded blocks were found to be that, when moulded on the dry side of the optimum moisture content, the appearance of the blocks looked very pleasing and beautiful, but after air drying for some days some hair cracks began to develop on the surface. The ones moulded at about 5% wet of the optimum gave blocks of good quality and very pleasing appearance with no cracks on them when air dried. It also gave a good compressive strength value. Those moulded on the wet side of the optimum with ratios between 1.2 and 1.4 gave a fine appearance but also developed some cracks after air drying for some days. Those in the ratio between 1.5 and 2.0 gave problems during the moulding and when moulded showed cracks on them which enlarged after air drying for some few days.

9.8.1 General comment on the most appropriate moisture content of moulding adobe blocks

It was observed that with the TEK block machine, the most appropriate moulding water content was between the ratios of 0.8 and 1.2 of moulding m/c to optimum m/c. Beyond both sides of this ratio range the blocks showed some cracks after drying. It is advised that the blocks should be moulded on the wet side of the optimum since the compressive strength was higher for those on the wet side than those on the dry side.

9.8.2 Determination of density of the blocks

The bulk density of the moulded block was determined by weighing the block and dividing by the volume of the block. Moisture contents of the moulded blocks were also determined by drying some of the soil mixture used for the moulding in an oven at a temperature of 105 C to 110 C for 24 hours. The moisture content obtained was used to calculate the dry densities of the blocks. The dry densities were found to be in the range of 1827.0 to 1987.0kg/m for the adobe blocks.

9.8.3 Crushing strength of raw soil blocks

After the air drying under the shed at a temperature between 22 C and 28 C for a period ranging from 14 days to 60 days, the blocks were then sun dried for 7 days and then sent to the BRRI concrete laboratory to determine their crushing strengths. The moisture content of testing and the weight of the blocks were also determined before testing.

Some results of the compressive strengths, moulding densities and moisture content, number of days of air drying and the water content of testing are summarised elsewhere in the report. The compressive strength of the adobe blocks were found except in three cases to be in the range of 40 to 130 psi with the higher values obtained for those moulded with the moulding m/c to optimum m/c ratios of between 0.8 and 1.2

9.8.4 Method of mixing soil with sand, time of mixing and moulding of blocks

After the trial moulding of the raw soil, the soil was then stabilised with sand. The laboratory technicians had earlier carried out trial tests in the laboratory to obtain the appropriate parameters for sand stabilization. It had been established that about 30% sand content gave the best stabilisation results both in appearance and in strength. With this information, the Santasi soil was stabilised with 30% sand. Sand stabilised blocks were then produced in the TEK block press.

The mixing was supposed to have been done with a mixer, but since the mixer had at that time not been purchased, the mixing was done by hand using shovels. It was also anticipated that since this technology was to benefit the rural people, there was a possibility that the villagers would not be able to purchase a mixer and would therefore be using shovel mixing. The mixing was done by two labourers using shovels on a wooden platform. With the optimum water contents and density relationships already established in the laboratory, moulding water content was defined. Each soil water (soil mass) was mixed thoroughly on the platform for 10 minutes. The mixture was then covered with polythene bags and wet sack to allow for curing and homogenisation of water for four days. After the 4 days curing, the moisture content of the mixture was determined and the moulding of the trial stabilised blocks made. The moulded stabilised blocks were air-dried under the shed at temperature of between 25 C - 28 C for a period of time ranging from 7 days to 60 days. After the air drying the blocks were sun dried at around 25-30 C for seven days before subjecting them to the crushing strength determination.

9.8.5 Crushing strength of selected sand stabilised soil blocks

The crushing of the blocks was carried out in the BRRI concrete laboratory using the Avery Compression Machine. Moisture contents at test were determined. The blocks were also weighed to determine the densities at test. The crushing strength results of the tested blocks are reported. The adobe production process using TEK block machine is illustrated in Fig. 9.11. Typical cured, scientifically produced adobe blocks are given in Fig. 9.12. Note the difference between the scientifically produced blocks and those produced by a rural unskilled moulder in a wooden moulds in Fig. 9.13. It is also noted that adobe blocks produced from raw micaceous soil started to disintegrate under the shed without being exposed to rain (Fig. 9.14); typical micaceous soil blocks exposed to rain for three months are almost back to the condition of soil (Fig. 9.15).

9.8.6 Mode of crushing

Crushing of the sand stabilised soil blocks were carried out at the BRRI concrete laboratory using the Avery Compression machine with the same process as was used for the adobe blocks.

9.8.7 Stress-strain relationship for crushed raw and sand stabilised blocks

Unfortunately, strain measurements were not taken during testing and as such stress strain graphs could not be plotted. It is hoped that strain measurements could be taken for subsequent tests. Trial lime stabilisation of the soil for blocks production was carried out using lime produced by the Building and Road Research Institute.

9.9 ESTABLISHMENT OF CRITERIA FOR SELECTING SUITABLE MATERIALS FOR RAMMED EARTH AND ADOBE BLOCKS

Criteria and specification developments for definition in earth construction is normally the result of laboratory, field construction and performance evaluation studies. Studies and review of existing specifications and Codes of Practices established elsewhere are also useful. Traditionally, certain empirical tests have been proposed for selecting natural soils for the production of bricks, adobe and rammed earth walls. Some of these tests include the following (Stulz, 1981; Habitat, 1986).

(a) Visual test

(b) Sedimentation test

(c) Wet shaking test

(d) Thread test

(e) Ribbon test

(f) Dry strength test

(g) Odour test

(h) Bite test, and

(i) Shine test

These tests could reveal a lot of information to an experienced or expert soils or materials technologist, but to a novice in the field, they can only represent preliminary field identification tests for selecting soils for the routine laboratory characterisation tests such as particle size analysis, Atterberg limits and shrinkage tests, compaction test, as well as other complicated strength, durability and weathering tests requiring sophisticated laboratory equipment. Mitchell (1976) and Ingles and Metcalf (1972) have shown that for a complete understanding of the fundamentals of the behaviour of raw and stabilized soils and, in particular, to help the soil technologist to select the most appropriate stabilizer, or combination of stabilizers the most important of which are cement, lime and bitumen, indepth study of the soils is necessary. For example, information available from laboratories where soil stabilisation studies are taken very seriously for low, intermediate and high technology building materials production, it is absolutely necessary for a complete fundamental analyses of the soil to be undertaken, including:

(1) Determination of structure and fabric

(2) Pore size analysis

(3) Determination of complete chemical composition:

a)	Silica	SiO_2
b)	Alumina	Al_2O_3
c)	Iron Oxide	Fe_2O_3
d)	Phosphorus pentoxide	P O
e)	Sulphur trioxide	SO_3
f)	Potassium oxide	K_2O

g)	Calcium oxide	CaO
h)	Magnesia	MgO
i)	Manganese oxide	$Mn\ O$
j)	Titania	TiO_2
k)	Sodium oxide	Na_2O
l)	Loss on ignition	LOI

(4) Determination of relevant Physico-chemical characteristics:

a) pH value

b) Specific surface

c) Salinity of groundwater

d) Cation exchange capacity

e) Exchangeable ions

f) Total soluble

g) Organic matter content

h) Hygroscopic (airdry) moisture content

i) Other deleterious constituents

(5) Determination of mineralogical composition:

a) Quartz

b) Kaolinite (including halloysite)

c) Mica (including illite)

d) Smectite

e) Carbonates

f) Feldspars

g) Allophane

h) Montmorillonite

i) Chlorite

j) Vermuculite, and

k) Gibbsite

(6) Determination of degree of crystallinity of clay minerals:

a) Crystalline

b) Amorphous

c) Content of total amorphous constituents

(7) Assessment of the degree of desiccation of the soil; this is significant in the case of soils containing unusual minerals such as montmorillonite, halloysite, allophane, etc.

These parameters will determine the trend of further research including the prediction of the chemical and physico-chemical properties of the raw soil or the reactions that would take place between the particular soil and a given stabiliser or combination of stabilizers.

In recent years, geotechnical engineering has attempted to add value to the criteria for selecting earth materials for building construction. The geotechnical tests identified as very useful are as follows:

(a) Particle size analysis

(b) Sand equivalent test

(c) Shrinkage test

(d) Plasticity tests (various forms of it)

(e) Compaction test

(f) Bearing strength tests

(g) Amenability of the soil to stabilisation with specific agents.

The key property of any soil is the particle size distribution and a rough idea of determining it is illustrated in a test known as sand equivalent test or sedimentation test. The result of such a simple test is shown elsewhere (see Fig. 10.1). Because particle size distribution is such an important characteristic of all soils most criteria have been based on particle size distribution envelopes in the first instance (see Figs. 10.2 which shows a typical texture classification chart for fine grained soils). In the area of defining suitable materials for adobe blocks and rammed earth, significant contributions have been made in terms of textural features by many investigators. These are illustrated in Chapter 10. Optimum grain size envelopes that have been proposed seem to emphasise the validity of the concept of ideal particle size distribution for obtaining optimum dry density (Fuller and Thompson, 1907). This concept has been widely utilised in earth engineering including dam and pavement construction. The theoretical basis as developed by Fuller and Thompson (1907) was meant to help identify optimum grain size distribution of aggregate for concrete. This has been successfully extended to soil selection for dam, pavement and building constructions. The supporting information are available in literature. The first attempt to identify ideal particle size distribution for lateritic soil buildings such as adobe construction appears to have been made by Hammond (1973) and recently by Gogo (1990). The texture, density ranges as well as the position of some soils found suitable for lateritic soil building and their plasticity characteristics have been given elsewhere (see Fig. 10.4). Considerable amount of work in defining optimum soils in terms of particle size distribution and plasticity properties as well as compaction characteristics for rammed earth, pressed earth and adobe have been reported by Hugo Huben and his associates (see Huben et al., 1989). The results have been based on studies on soils from different parts of the world and are summarized. Before any conclusions can be made in transferring the existing knowledge of laterite soils we need to get some idea about major differences between natural soils and pedogenic materials of which lateritic soils are a group. The comparison of the two material groups is given in Table 9.6. It is interesting to note that bar shrinkage test which is a useful test for identifying soils for brick and tile manufacture is also a very useful test for defining earth building soils. An example of the bar-shrinkage test result is shown elsewhere (see Fig. 10.5). Based upon the above literature survey results, we proceeded to define tentative specific suitability criteria relating to the selection of laterite soils for adobe blocks and rammed earth construction in Chapter 10. The result of the study did show that the soils should be well graded. The selection of a particular material has to be based on trial laboratory characterisation, trial moulding of blocks and construction of experimental or an exposure wall to observe the behaviour with time. In the case of rammed earth, the same principle of materials selection is valid. However, more gravelly materials can be allowed for thicker walls. The maximum particle size will depend, however, on the thickness of the proposed rammed earth wall. For the wall thickness of between say 0.25 to 0.3m maximum, gravel size of 25 millimetre may be allowed with passing 200 size (0.75 millimetre) falling within 15 and 30 per cent. In every situation, trial tests have to be undertaken to obtain optimum grading envelopes and satisfactory performance record in relation to the environment.

The features and compaction (by pressing) characteristics of the TEK block machine compared with the Cinvaram press are given in Table 9.7.

A typical empirical soil rating chart for selecting soils for adobe blocks production was proposed by Fitzmaurice (1958); this is given in Table 9.8.

10.0 PROCEDURE FOR EVOLVING SUITABLE MATERIALS SELECTION CRITERIA FOR THE PRODUCTION OF ADOBE BLOCKS AND RAMMED EARTH WALLS

10.1 INTRODUCTION

In principle, all soils can be used for production of adobe blocks and rammed earth walls without altering the properties through the addition of any stabiliser. This is because where a single soil is not applicable, a series of soils can be blended through mechanical stabilisation to achieve a certain particle size distribution, plasticity characteristics and linear shrinkage to enable the materials to be used. Another approach to modifying the soil property mechanically is to remove some undesirable particle sizes to make the soil amenable to utilization in producing adobe blocks and rammed earth walls. The exceptions, however, are certain unusual type of soils such as highly organic soils, dispersive erodible and collapsible soils. For such soils, there are standard methods and procedures for improving their properties through many geotechnical engineering procedures including mechanical blending and stabilisation with cementitious materials. Within the framework of identifying soils for the production of adobe blocks and rammed earth walls, an important indicator of soils suitability or not lies in their conformity with certain grading (particle size) characteristics.

10.2 LITERATURE REVIEW

One of the early criteria for selecting suitable materials in terms of definition of particle size distribution was by the so-called sedimentation or sand equivalent test (fig.10.1). Later studies led to the development of a series of ideal grading envelopes for many regional soils mainly from Europe and North America (SKAT, 1988; Doat et al., 1979; and Hugo et al., 1989) (Fig. 10.2). The position of these materials on the Casagrande plasticity classification chart (Casagrande, 1948) have also been defined (Fig.10.3) for these regional soils. The relationships for some of the suitable soils between the dry density and the moisture content have also been established (e.g. Hugo et al., 1989) (Fig. 10.3).

With regard to the use of cement and lime stabilised soils for building construction many pioneering works have been carried out (e.g. Fitzmaurice, 1958; Alcock, 1958; Webb et al., 1950) and recently, by UNIDO (UNIDO, 1987) and United Nations Centre for Human Setlements (UNCHS-Habitat, 1986). However, for the purpose of this chapter, we are dealing with non-cementiously stabilised soils. In Ghana, the first attempt to study the possibility of identifying unstabilised soil for rural housing construction was made by Hammond (1973) (Fig. 10.4). Considerable work on the use of stabilised lateritic soils for block production were undertaken by Okine (1971); Bawa and Bartel-Konacka (1964); Bawa (1965); Bawa and Gidigasu (1965); Sperling (1961, 1962); Coad (1979); Lund (1980); WABRI (1957). In selecting soils for cement stabilisation for housing construction in Ghana, great emphasis was put on the so-called bar/linear shrinkage test (Okine, 1971).

10.3 SCOPE OF WORK DURING THE PROJECT

Experience gained during this study for highly micaceous sandy soil formed over muscovite-biotite, granite, and the highly silty clay soil formed over phyllite-schist showed that though the two soils showed the same bar/linear shrinkage characteristics (Fig. 10.5), adobe blocks produced from them in the TEK block machine revealed that blocks produced from the micaceous soils deteriorated faster under room temperature condition while those produced from soil formed over phyllite (see Figs. 9.14 and 9.15)) performed better. This brought into focus the need for modern approach to residual soil identification and classification for the production of adobe blocks and rammed earth walls in which emphasis should be placed not only on the particle size distribution, plasticity properties and bar/linear shrinkage but more importantly on the compositional factors of the soil, particularly the chemical and mineralogical composition, the physico-chemical properties as well as the degree of weathering and desiccation. This has been discussed in detail in Chapter 9 of the report. The importance of evaluating the performance of existing earth buildings in relation to the nature of the materials, the construction technology as well as the operative, climatic and environmental factors should form part of field tests to evolve reliable suitable soil selection criteria. In this study, the literature review is followed by results of field performance studies in the four main climatic zones of Ghana. These are discussed in detail in Chapter 7. This is followed by results of studies on exposure walls built with adobe blocks, rammed earth and lime stabilised lateritic materials, at Fumesua (see Chapter 13). Very interesting results were obtained during visits to the various climatic zones to take samples from existing walls where this was possible as well as borrow areas from where the soils were won for the construction. Cognisance was taken of the various degrees of desiccation of the materials in the walls and those from the borrow areas. The results of the field studies in terms of the climatic zone, the housing construction technology, the performance of the building in relation to the climatic zone as well as the classification characteristics (i.e. particle size distribution, linear shrinkage, and plasticity characteristics) are given (Figs. 10.6-10.11 and Tables 10.1-10.3) according to the climatic zone. Materials were also taken from borrow areas, particularly from the semi-arid climatic zone of the north where some people did not take kindly to materials being taken from their dwelling walls. In such circumstances, materials were randomly sampled from borrow areas especially in areas where adobe or any other earth method of building construction have been successful. With the project execution, it was found that all unstabilized soils failed durability, weathering, wet-strength, volume stability, and degradation tests and yet some buildings whose roofs had been ripped off over ten years ago still have their walls standing in the face of rain, storm, and sunshine without disintegrating. Examples of these walls are shown in Fig. 10.10. The grading curves of soils samples taken from the exposed walls are shown in Fig. 10.11). The implication here seems to be that materials that have been placed in the walls do undergo some processes of micro-structure development and surface coating that make them resist the adverse effects of the climatic conditions. It is anticipated that a deeper scientific study of the phenomenon of lateritic soil desiccation and associated micro-structure development in exposed walls which make them sustain adverse climatic conditions without collapsing for a long time needs to be undertaken as part of the programme of local materials development at the Building and Road Research Institute. Finally, based upon the examination of the results of literature search, existing local information analysis, results of studies on field performance of existing earth building technologies in relation to various climatic zones as well as limited data collected from studies on exposure walls built at Fumesua, series of tentative criteria for selecting unstabilised lateritic soil for the production of adobe blocks and rammed earth walls are proposed in relation to the Atakpame, wattle and daub and adobe walling technologies. This criteria is, by no means, conclusive. It is expected that studies relating to indoor climatic conditions including levels of indoor comfort will follow through instrumentation of the demonstration buildings constructed in the various climatic zones and monitoring of the physical conditions of the buildings will also be carried out concurrently.

Based upon the evaluation of the results of studies on the performance of the earth buildings in the climatic zones, optimum suitability, grading envelopes and plasticity and linear shrinkage ranges have been established in Fig.10.12-10.14 and Table 10.4.

11.0 DEVELOPMENT OF SMALL-SCALE TECHNOLOGIES FOR THE PRODUCTION OF LATERITIC STONE BLOCKS

11.1 PRODUCTION AND USE OF LATERITE STONE BLOCKS FOR HOUSING CONSTRUCTION

The project sets out to establish the suitability of lateritic stone deposits for the production of dimensional stone blocks for the various types of rural housing construction. Results of some preliminary studies carried out under the IDRC laterite housing project showed that already a few laterite stone buildings exist in some parts of the country. Further to this, some good outcrops of laterite stone were located and mapped in various parts of Ghana. With existing knowledge on improved methods of stone processing technologies, it appears desirable for enhancing Ghana's housing construction industry to utilize the great potential offered by the lateritic stone deposits to increase the country's housing delivery capacity especially in the rural areas where financial resources are scarce and the lateritic stones are in abundance.

11.2 SCOPE AND OBJECTIVE OF THE STUDY

(a) To define criteria for locating the opening up of lateritic stone quarries.

(b) To develop the technology of cutting and producing lateritic stone blocks for building construction.

(c) To carry out both field and laboratory testing and characterisation for the selection of the most suitable lateritic stones for blocks production.

(d) To train interested youngmen to produce blocks from laterite stones as a means of livelihood.

Lateritic stone quarries were opened up in the arid climatic zone (Bolgatanga and Bawku); dry sub-humid zone (Techiman) and moist sub-humid zone (Kokoben-Kumasi, and Traboum-Kumasi) as three main study areas.

The investigation was carried out in five (5) phases as follows:

(a) Identification, location and mapping of laterite stone deposit or hardpan outcrop.

(b) Development of procedure for opening laterite stone quarries and training of unskilled labour on the production of blocks for commercial purposes.

(c) Evaluation of geotechnical properties of the laterite stones and boulders.

(d) Development of cutting procedure for lateritic stone blocks and construction of exposure walls using the blocks.

(e) Evaluation of performance of existing lateritic stone buildings as a basis for developing standards, specifications and Codes of Practice for laterite stone block building construction.

11.3 LOCATION OF LATERITIC STONE DEPOSITS

The availability of basic regional geological maps greatly facilitated the search for laterite stone deposits. Such maps immediately indicate areas or localities where different types of stones are likely to occur. For example, the establishment of an inventory of laterite stone resources in the Techiman district was facilitated by the use of geological maps. Laterite stone deposits identification may be made possible using the following indicators:

(a) Signs of previous local use of laterite stones.

(b) Cliffs, road cuttings, hill crests and other prominent landscape features, which usually serve as indicators of the occurrence of laterite stone deposits.

(c) Areas of scanty vegetation also make it possible to locate lateritic stone at shallow depths.

11.4 FORMATION AND NATURE OF LATERITIC STONES

Laterite materials, including lateritic stones are known to be associated with and may develop on all rocks containing alumino-silicate minerals (Gidigasu, 1976). Studies on the relationships between laterite soils and parent material (Sherman, 1952; Nye, 1955; Brammer, 1962; Maignien, 1966; Loughnan, 1969) have shown that lateritic materials may overlay a variety of parent rocks such as granites, granulites, gneisses, schists, phyllites, and volcanic ash. Lateritic stones were also identified over shale, sandstones, and limestones (e.g. Cooper, 1936; Brammer, 1952; Hamilton, 1964; and Dowling, 1966). Maignien (1966) also observed laterite stone on alluvial and colluvial materials. Indeed one could say that lateritic materials could develop provided there exists an adequate supply of oxides and hydroxides of sesquioxides of alumina and iron, including sesquioxide rich materials, and good internal drainage conditions and appropriate pH medium. In each case, the level as well as stages to which the lateritisation process could proceed to, would depend on the nature and the extent of the physico-chemical weathering, the primary rock forming minerals and the nature of the weathering process determined by the soil-forming factors including parent material, climatic-vegetational conditions, topography and drainage conditions, the pH condition of ground water, and the period of time for which the weathering processes have operated. The sequence of residual chemical weathering and formation of lateritic materials including lateritic stone is illustrated(see fig 5.8& 5.9) Lithological and geotechnical implications of lateritisation are also illustrated in Figs.4.2 and 4.3. Experience from laboratory and field studies have revealed that the formation of laterite materials involves the transformation of massive rock systems of primary feldspar, quartz and ferro-magnesian minerals to apparently porous clayey systems containing kaolinite, sesquioxides and some residual quartz. If the sesquioxide rich horizon remains covered by several feet of soil, it may remain relatively soft or slightly hardened so that it can still be penetrated by plant roots. Such material can be dug out with pickaxes under the moderately firm conditions and may break to angular fragments when dropped or struck (Gidigasu, 1976). If the horizon is exposed at or near the surface, the removal of soil from above triggers off a hardening process. This hardening or induration process appears to be partly a further oxidation and partly a re-oxidation and crystallization of the iron constituent compounds under the influence of alternate wetting and drying conditions, ending up in hardened crusts (cuirasse) or hardpans of rock-like structures. Generally, the lateritic stones may be grouped as shown in Fig. 4.4.

11.5 LOCATION OF LATERITIC STONE OUTCROPS IN GHANA

The study of Black and White panchromatic aerial photographs showed laterite cuirasses and hardpans in places of sparse vegetation associated with very little or no agricultural activity. These laterite materials assume cap position on hill crests and appear in airphotos as pavements in these topographic heights. Figure 11.1 shows probable locations of lateritic stones in Ghana.

11.6 QUARRYING AND WINNING OF LATERITIC STONES AND BOULDERS

By means of the jointing and fractures in the laterite hardpan, chissels were used to wedge lateritic stone blocks apart; gradually developing a laterite stone quarry. The layering and stratification in some laterite stone deposits make it possible to obtain the material in slabs of desirable sizes, a property which enhances the rapid development and production of laterite blocks.

Under Ghanaian conditions we have identified three groups of lateritic stone materials. The first group is lateritic boulders which have to be identified through excavation of lateritic soil deposits. The maximum dimension of such boulders may be up to a metre in diameter. For example, Fig. 11.2 shows labourers at work trying to locate and win this type of boulders. The second type of lateritic stone (lateritic hardpan) deposit overlies lower soil layers, namely the mottled and pallid zones of typical lateritic soil profile. Typical profile in which we find the second type of lateritic stone capping soil layers have been illustrated earlier (see Fig. 11.3) in the first technical report.

The best method of winning this lateritic stone is by chiselling or through the use of pickaxes. Where the deposit is very thick blasting may be carried out. The third type of lateritic stone is the one where a thick layer directly overlies partially weathered parent rock as shown in Fig. 11.4 This lateritic stone overlies sandstone at very high altitude with very good internal drainage condition; this type of lateritic stone is easily won through chiselling, crushing with appropriate equipment or blasting. Typical pieces of lateritic rocks are given in Fig. 11.5 Under field conditions the colour of lateritic materials may vary with topographic site (Gidigasu, 1976) indicating the state of the predominant iron oxide and degree of dehydration or desiccation.

11.7 GEOTECHNICAL CHARACTERIZATION OF LATERITIC STONES AND BOULDERS

The induration and hardening of laterite materials result in the production of soft to moderately hard members, which finally end up with laterite hardpans and cuirasses. These extreme processes of lateritization render some of the lateritic materials non-granular as compared with laterite gravelly soils and laterite gravels where geotechnical properties should normally have been determined by such standard tests as grain-size distribution, Atterberg limits, and compaction characterisation. It, however, became apparent that three standard laboratory index tests could be undertaken on laterite stone blocks for the overall assessment of their durability and strength characteristics; these are (table 11.1):

1. Water absorption test

2. Specific gravity test

3. Uniaxial compressive strength test

The heating and wetting test was also carried out elsewhere to evaluate durability (de Graft-Johnson et al., 1969). Some of the results obtained are summarized, Ranges of crushing strengths reported elsewhere are also given in Table 11.2 It is obvious that some of the laterite stones possess crushing strengths equivalent to medium to hard natural stones (e.g. Duncan, 1970).

There is a notable problem with the cutting of heterogenous lateritic stones and boulders into blocks for crushing strength test. Fig. 11.6 shows a technician attempting with difficulty to cut a lateritic boulder into form using standard stone cutter. The result is that we get uneven, irregular blocks; some of which are shown in Fig. 11.7 . It is envisaged in the project to develop a lateritic stone-cutting machine; this will provide a sound solution for mass production of lateritic stone blocks for commercial purposes.

11.8 PRODUCTION OF LATERITIC STONE BLOCKS

By means of simple tools such as pickaxes, chisels and hammers, the hard laterite stone layer is broken down into boulders of various sizes.

11.9 RURAL HAND AND HAMMER METHOD

In rural areas, laterite blocks are produced by using simple hammers and chisels to trim the stones into desirable shapes. The size and hardness of a particular stone/boulder determines the amount of force required and the type of hammer to use to cut the stone to smaller sizes.

11.10 CHARACTERISTICS OF THE BLOCKS PRODUCED BY HAND

Hard lateritic stone layers are usually heterogenous both structurally and texturally. As a result, the process of breaking these slabs into blocks produces non-uniform sizes and irregular shapes. These blocks often lack the rectangular block geometry traditionally used for building. The edges of lateritic stone blocks are not well defined thus producing laterite stone blocks of various geometry.

11.11 RISK OF HARMING HANDS OF WORKERS

Usually, rural laterite block producers do not wear protective clothing to protect hands, eyes and the entire body. Indeed, wedging, hammering and breaking of laterite stone boulders into blocks pose very serious risks to workers. Hammering of laterite stone boulders could produce fragments which fly to hit any part of the body, and human hands have always suffered from the impact of stone boulders.

11.12 PROTECTION OF WORKERS

Rural workers who produce laterite stone blocks should be protected by means of eye shades, hand gloves, head helmets and field protective boots. These simple devices are able to protect the body including the eyes, head, hands and the legs.

11.13 COST OF PRODUCTION AND MARKETING POTENTIAL OF LATERITE STONE BLOCKS

At the local level, the unit price of a standard stone block was compared with that of sandcrete block of equivalent size (Table 11.3) This was followed by the demonstration in terms of building costs per unit prototype wall and/or house with other construction materials, notably sandcrete blocks, natural stone, brick house, taking into account the benefits of long-term lower maintenance costs of the various options.

National institutions and organisations involved in rock quarrying, mining and training in the fields of engineering geology, building technology, architecture, etc. should be sources of information concerning national housing supply and demand capacity. Stone materials should be compared with other building materials in order to establish possible potential and market forecasts of lateritic stone for the overall production planning.

The existence of stone houses in some parts of Ghana and the establishment of an improved technology for the production of lateritic stones will greatly help to boost higher market demands for the stone blocks since the district capitals have fairly large markets.

11.14 PRODUCING LATERITIC STONE BLOCKS WITH STANDARD STONE CUTTERS

Laterite stone blocks could be produced more effectively and efficiently by means of modern stone cutters, chisels and steel wedges. Most of these modern stone cutters are power operated (disc) saws which provide straight geometric cutting within desired operational costs. Also accompanying these modern stone cutting devices are protective head shields, eye-shades and hand gloves which minimize their operational risks. Lateritic stone cut into shape ready for crushing strength test is shown in Fig. 11.8

Crushed blocks do not give traditional failure pattern but simply collapse along the weakest shear planes (Fig. 11.9).

11.15 SUITABILITY OF STONE CUTTING TECHNOLOGY IN RELATION TO THE ORIGIN, STRUCTURE, CEMENTING MATERIAL (IRON OR ALUMINA) AND HARDNESS

Modern stone cutting machines, with power may not be suited for the cutting of the heterogenous, indurated, hardpans and lateritic stones for the production of blocks as the constituents of these hard laterite stone layers are essentially coarse particles or quartz pebbles set in a matrix of iron or aluminium oxide. Hard laterite stones with very hard mineral constituents are better cut into blocks by manual methods since sawing might destroy and hinder the efficient cutting of the material into blocks. Laterite stones with moderate hardness which do not crumble easily under any mechanical devices could be cut into desired blocks by means of modern power cutters and/or simple hand hammer methods. Those laterite stones which crumble as a result of weak cementing material or due to weak structure, may be found undesirable since this type of material may not present any solid shape desirable for block cutting.

11.16 TRAINING

Training of interested young men in the area of laterite stone block production is highly desirable, particularly for people who intend to enter into the laterite stone block production trade on a large scale. Effort is also to be made to acquaint students of engineering, earth sciences and architecture with the knowledge of the laterite stone construction technology in the University at Kumasi. The initial training of people at Techiman involved at least four young men who were assisted through financial incentive to develop the laterite stone quarry in order to produce blocks for sale to people for building construction as a means of their livelihood. It is the hope of the IDRC laterite project that this will later be extended to a greater number of trainees through expansion of the programme at the district and regional levels through Ghana Government support.

11.17 EQUIPMENT AND TOOLS

Simple tools such as pickaxes, hammers, steel wedges, chisels, cutlasses, eye shades, gloves and field boots were used by the trainees; these equipments were provided from their earnings from IDRC funding. The future desire of the local population to use this technology for the production of laterite stones for building shall, however require in addition to the above tools, improved tools and equipment such as cutting saws, explosives for blasting, together with loading and transport facility for future large-scale commercial blocks production.

11.18 POTENTIAL WIDER USE OF LATERITIC STONES FOR CONSTRUCTION IN TROPICAL DEVELOPING COUNTRIES

Laterite rocks occur widely in the tropics within most geological formations and climatic conditions (Bhatia and Hammond, 1970; Gidigasu, 1976). These materials occur either as fairly soft materials capable of hardening on exposure to air or they are rocklike insitu depending upon the topographic site, the climatic zone and the chemical composition (e.g. Gidigasu, 1976). Chemically, two main types of lateritic stones have been identified in Ghana, namely the ferrogenous and the aluminous lateritic stones.

The geotechnical properties of typical laterite stones and boulders identified in Ghana have been evaluated and results have been by De Graft-Johnson, Bhatia and Hammond (1970); Gidigasu (1976, 1980); and Gidigasu and Kuma (1987). For example, the uniaxial crushing strengths reported for typical West African lateritic stone at the Transport and Road Research Laboratory, United Kingdom, vary between 196.8 and 316.4kg/cm^2 (Shergold, 1945) while typical Ghanaian ferruginous lateritic stones gave crushing strengths of 173.8kg/cm^2 (e.g. Obeng, 1970).

11.19 POTENTIAL USE OF LATERITIC STONE AGGREGATES AS CONCRETE AGGREGATE

Typical ferrogenous laterite stones from the northern semi-arid climatic zone of Ghana (Bolgatanga and Bawku) crushed and sieved through appropriate set of sieves to conform to the British Standard (BS 812; 1961) particle sizes of 3/4" and 1-1/2" maximum lateritic aggregate sizes are illustrated (see Fig. 11.9a) Concrete cubes of standard sizes were prepared with mix design of 1:2:4 and water-cement ratio of 0.5. Eighteen cubes were prepared for each aggregate type, cured for 24 hours under wet sack followed by immersion in water for periods of 7, 28, 60, 120, 180 and 360 days before testing. Average uniaxial crushing test results obtained for 3 cubes for each curing period are shown in

Figs. 11.9b and Table 11.4 Figure 4.13d summarises the main results of the studies on strength development with time of the two lateritic stone concrete cubes. It is noted that on the average, the 28 days cured sound natural rock aggregate concrete strength of 210kg/cm^2 can be obtained if care is taken to select hard lateritic stones from well-drained sites where they have undergone considerable desiccation and dehydration.

12.0 STABILISATION OF LATERITIC MATERIALS WITH LOCALLY PRODUCED LIME FOR WALLING BLOCKS PRODUCTION

12.1 INTRODUCTION

In the area of soil-cement or soil-lime stabilisation for road construction there has been very little success in Ghana because very few indepth studies had been undertaken.

It is not true that lateritic soils by nature are not amenable to stabilisation for engineering purposes; considerable success has been reported elsewhere in Africa (e.g. Bulman, 1972). The difference is that the construction should normally be preceded by a thorough laboratory as well as field trial studies; these have not been done in the past and it was quickly concluded that locally produced lime cannot be used to improve the quality of soils for construction in Ghana. For example, there is lack of data on scientific laboratory studies on the importance of compositional and environmental factors to the engineering behaviour of lateritic soil-lime stabilised mixes in structures. These setbacks should not discourage us because about 70% of the surface of Ghana is covered with lateritic materials (including gravels and stones) and lime can be cheaply produced on commercial scale from huge limestone and dolomite deposits as well as the lower Volta clam shells. What is required is thorough investigations into lateritic soil-local lime stabilisation characterisation to arrive at conclusive and meaningful results that may be utilised for both building and road construction purposes.

It has been indicated in the First Technical Report that limestones and clam shells are abundant in Ghana and small-scale rural technology of producing lime from these raw materials have been developed. Logically, one of the objectives of the study is to investigate the possibility of improving the engineering properties of the clayey lateritic soils through stabilisation with lime locally produced from dolomitic limestone and high calcium clam shells. Laboratory trial studies on the lateritic soil-lime stabilisation had been carried out in the past, but the results obtained (e.g. Coad, 1979; Lunt, 1980; Bulman, 1964, 1972) indicated that local application of lime stabilisation using local raw lateritic soils is feasible and should be persued. The production of lime from dolomitic limestone and the clam shells by the Materials Division of the Building and Road Research Institute (BRRI) was utilised in the study. The main aim was to try to use local lime-lateritic soil stabilisation to cater for areas where lime can be produced cheaply and where the available soils are so clayey that even sand stabilisation alone may not give the desired strength results. Indeed, it is anticipated that small-scale local lime production should be encouraged as a rural industry to generate employment. This aspect would be fully explored and the rural dwellers would be assisted to produce lime on their own and to carry out soil-lime block production for constructing rural houses through self-help and community participation.

Lime-soil stabilisation is one of the oldest ways of improving fine-grained soils for construction purposes. The local soil-lime block production capacity would depend on the quality and quantity of the lime, the nature of the soil, the laboratory procedure for evaluating the lime and the soil-lime mixes, the method of moulding the blocks, the curing procedures and the age of the blocks. In road construction in Ghana, because of the high ground heat, imported cement stabilisation has been posing problems since the maximum time of two hours from start of mixing, watering and moulding of soil-cement blocks should be maintained to ensure adequate strength development. Lime, on the other hand, does not have this limitation and long delay between the mixing and moulding may not adversely affect the block strength development since the strength development processes are more or less physico-chemical.

12.2 LIME CHARACTERISTICS

The key material is the lateritic soil. The next key item is the lime itself. In the following existing information on the nature and technology of local lime production (Bawa and Kornacka, 1964; Ayetey and Gogo, 1973) are first reviewed. There are various types of limestones. The dolomitic ones are for our purposes, only useful for producing white washing materials, the high calcium ones are useful for the production of cement, etc. Small deposits of limestones that do not merit the setting up of cement factories are those that we are concerned with.

The next item is water. In the foregoing, the steps and processes of lime stabilisation for small-scale block production for rural housing using lateritic soils is now discussed.

As a first step we have to know the product lime itself and how it is produced. As indicated elsewhere, lime is also obtained as a by-product in the form of lime sludge (which contains calcium carbonate and various impurities) from sugar manufacture, and from acetylene and paper industries.

The chemical reactions in lime burning are:

Reaction 1: (900 C, depending on type of limestone)

$CaCO_3$	+ heat	$\longrightarrow$ CaO	+	CO_2
Calcium carbonate		Calcium oxide		Carbon dioxide
Limestone Chalk Coral/Shells		Quicklime Lump lime		

or

Reaction 2: (at around 750 C)

$CaMg(CO_3)_2$	+ heat	$\longrightarrow$ $CaCO_3$	+	MgO	+	CO_2
Dolomitic limestone		Calcium carbonate		Magnesium oxide		

Hydration

The type of lime that is used for building and numerous other processes is **hydrated** or **slaked lime.** This is obtained by adding hot water or steam to quicklime. Pure quicklime reacts vigorously evolving considerable heat, while impure limes hydrate slowly, or only after the lumps are ground.

Reaction 3:

CaO	+	H_2O	$\longrightarrow$	$Ca(OH)_2$	+ heat
Calcium oxide		Water		Calcium hydroxide	

Three forms of hydrated lime are commonly produced:

(a) **dry hydrate,** a dry, fine powder, formed by adding just enough water to slake the lime, which is dried by the heat evolved;

(b) **milk of lime**, made by slaking quicklime with a large excess of water and agitating well, forming a milky suspension;

(c) **lime putty**, a viscous mass, formed by the settling of the solids in the milk of lime.

The most common form is dry hydrate, which is very suitable for storage in silos or air-tight bags, and easy to transport. Lime putty, which is an excellent building material, can be stored indefinitely under moist conditions. In small limeworks, slaking is usually done by hand, either on platforms to produce a dry hydrate or in shallow tanks to make lime putty.

Although the hydration of quicklime is a simple process, it must be carried out with special care, for instance, to see that all the quicklime is completely slaked. Pieces that hydrate too slowly and as a result are overlooked, can cause serious problems later on.

If water is added too slowly, the temperature of the lime may rise too fast, forming an active white gritty compound ("water burnt" lime). If water is added too quickly, a skin of hydroxide may develop, preventing further hydration ("drowned" lime).

Lime has been used for improving the quality of soil for construction over 2000 years and it is the sole cementitious material in certain parts of the world because of its abundance, ease of use and other benefits such as long slow strength development. Studies over the years have established that the degree of success of soil-lime stabilisation depends upon a number of factors, especially, compositional factors of the soil, mode of soil-lime preparation, environment and time of curing before testing (Fig. 12.1). The significance of lime content and reacted lime, period of curing on strength development of lime stabilized typical tropical reddish to brownish soils on strength is illustrated in Fig. 12.2.

12.3 SOIL-STABILIZER REACTIONS

12.3.1 Natural soil-cement reactions

The mechanism by which strength is gained in soil-cement mixtures is believed to depend on the development of chains or aggromerations of hydrated cement and soil grains which enclose voids and soil pockets in a three-dimensional skeleton. It is apparent that strength gain will occur whether clay minerals are present or not.

It has been suggested, however, that the mechanism of cementitious action is in part a surface phenomena and high specific surface area of the clay minerals may therefore give them an important role in soil-cement stabilisation (e.g. Gillot, 1968).

12.3.2 Soil-lime reactions

Three principal processes are thought to take place when lime is added to a clay containing soil. These are a rapid exchange reaction, a much slower reaction between the clay minerals and the lime, and carbonation of the unused calcium hydroxide by CO_2 present in pore solutions and gases. The strength gain by soil arises from chemical reactions between the lime and clay-grade minerals. When these are absent or present in small amounts use may have been made of lime together with a pozzolana (Gillot, 1968). The effect of compaction pressure, and curing period on lime-lateritic soil stabilised and cement/lime bauxitic soil stabilised soils on strength development are illustrated in Figs. 12.3 and 12.4. A number of international criteria for selecting soils for lime stabilisation using particle size passing No.200 sieve size, liquid limit, plasticity index of the soils have been published elsewhere (Figs. 12.5-12.7).

12.4 LOCAL LIME STABILISATION STUDIES

Figure 12.8 illustrates the flow chart for the laboratory lateritic soil-local lime stabilisation programme for the project execution. The effect of local lime on the plasticity characteristics of a typical lateritic soil is shown in Fig. 12.9. The relationship between the lime content, mixing time, sand and lime contents, and the linear shrinkage of a typical local lateritic soil is also shown in Figs. 12.10 and 12.11. Mixing of the soil-lime-water was done in the Hubbard mixer for a period of 20 mins. First, the lime was added to the dry soil in the proportion of 3%, 5%, 7% and 12% and thoroughly mixed in a tray before transferring the mixed sample into the Hubbard machine. The required water was then added and the mixing in the machine continued for 20 minutes before the compaction test was carried out on the soil-lime mixture.

The BS Standard (Proctor) compaction was employed in defining the dry density-moisture curves for the lime stabilised soil samples. For example, the maximum dry density for the

Santasi soil ranges from 1.58Mg/m^2 for the 12% lime content to 1.76Mg/m^2. The effect of lime stabilisation on the dry densities is illustrated in Figs. 12.12-12.14. Some results relating to lime stabilisation effect on the California Bearing Ratio (CBR), density and weathering test results are also given in Tables 12.2-12.3

12.4.2 Atterberg limits of lime stabilised soil

The material used was the percentage passing No.0.42mm sieve (BS No.36). The local lime was then combined with the soil in the required proportions of 3%, 5%, 7%, and 12% lime. The soil, before adding the lime was airdried. As expected, we noted that the plasticity index decreased with increasing lime content as has been reported elsewhere (e.g. Bawa and Hornsby-Odoi, 1965) until after 7% lime content when it started to increase again. Effect of lime stabilisation of Fumesua micaceous and Santase soils are summarized in Table 12.1.

12.4.3 Crushing test of cured specimens

The specimens were crushed using unconfined compression test. The rate of loading was 1.25mm per minute which continued to failure. Three specimens were crushed for each moulding condition and the average value of the three test results were defined.

Relationships between the compressive strength on the one hand and the moulding dry density, moisture content and percentage of stabilisers on the other hand, have been established. For example, the results of studies on the effect of lime stabilisation on the uniaxial strength development is illustrated in Figs. 12.15-12.24 and Table 12.1.

12.4.4 Characterisation of lateritic raw soil, soil-sand, soil-lime for the manufacture of test specimens

(a) Raw and sand stabilised soil moulded specimen

The study has shown that uniform moisture distribution of the soil is achieved when the soil is kept in air-tight containers at a controlled room temperature of 20 °C for at least 24 hours. This appears to give maximum workability and ease of sample moulding.

(b) Lime Stabilized Soil

For the lime stabilized soil it is obvious that the sample preparation includes a thorough mixing of the lime-soil with appropriate quantity of water. It has been established that some delay between mixing time and moulding does not significantly affect strength development of lime-stabilized soils, however, to achieve maximum benefit the delay should be kept to the minimum. For the lime stabilisation only 3-5% lime appears to be sufficient for achieving the optimum strength. The choice of whether to use sand or lime for stabilisation or a combination of them would depend on availability of the additive as well as the strength, durability and workability requirements. However, it is easier to work with sand since handling lime may be harmful depending upon the form of the lime.

12.4.5 Production of soil-lime blocks

Use of ordinary white or fat lime in the stabilisation of soils for road construction or soil-lime blocks for building construction is well established. Lime combines chemically with certain constituents such as silicates and aluminates in the soil to form stable compounds resistant to water. Also dimensional stability of the soil is improved by modifying the character of the clay fraction of soil by base exchange. Lime replaces the sodium or potassium ions in swelling types of clays to give more flocculent calcium clays which have less affinity for water. In the areas south of Sahara, from Senegal to Congo, the material normally used for the construction of walls is block made from a mixture of Portland cment and sand and known as "sandcrete" block. The compressive strength of these blocks usually varies from 150lb/in^2 to 500lb/in^2 in the case of non-vibrated blocks of 1:6 cement sand mix. Blocks with as low as 160lb/in^2 have been used on a major project (Sperling, 1961). Some trial mix designs were tried using locally produced lime; a weathering test reported by Bawa and Konacka (1964) on them are given as follows:

Material	Mix proportion (by weight)	Wet compressive strength (9 days) lb/in	Loss after 12 cycles of durability test (gravel) %
Lime:Sand	1:3	800	0.0
Lime:Lateritic soil	1:10	152	2.45
Cement:Lateritic soil	1:20	252	15.8

The project execution has in its programme local lime stabilisation of representative soils from the four climatic zones for the production of blocks. Laboratory studies on 4in by 8in samples has not been conclusive but some information on previous studies on two Ghanaian soils from Kumasi area are available. The results of studies reported by Coad (1979) and Lunt (1980), are summarized in Table Tables 12.4 and 12.5. The Cinvaram press was used; this provides pressure of only $2 kg/cm^2$. The strength and water absorption properties are not very encouraging but it does appear that if the pressure level is increased, higher strengths would be developed. Indeed, Lunt (1980) reported that with increased moulding pressure of lime stabilized soils erosion (weathering) can be reduced and possibly eliminated. Lunt (1980) compared the properties of various types of brick/blocks and from the conclusion reached (Table 12.6) it appears that lime stabilised blocks compare favourably in quality to other bricks and blocks. The problem, however, remains that the local lime is not pure; it contains a lot of impurities and more studies are required to refine the local lime production processes and quality control of the stabilisation products through appropriate specification developments.

It was easy to see the effectiveness of stabilisation in terms of the smoothness of the samples. Crushing strength obtained did not necessarily reflect the expectations of the result obtained through laboratory evaluation but it gives an idea as to the workability and the moulding moisture content and density; it also provides the basis for defining how much lime should be incorporated. For example, it was found out that some sandy soils have to be blended with clay to be found suitable. In that case, the fines fraction has to be determined for stabilising them (sandy soils) in order to obtain desirable adobe block characteristics.

In defining criteria for lime stabilisation of lateritic materials some information are available in existing literature for temperate and tropical zone natural soils where the significant soil properties are found to be the plasticity index, the liquid limit and fines content. Some of the charts proposed have been reproduced from existing information for temperate zone soils. Based upon extensive studies on regional soils by Hugo et al. (1980) specific grading envelopes and positions on the Casagrande plasticity chart have been proposed for selecting soil for lime and cement stabilisation. Some of the outputs of the study have shown that though the results are applicable to some extent, for every local soil type, preliminary studies both in the laboratory and in the field are imperative before realistic specifications can be formulated.

The conclusions amply demonstrate that raw and local lime stabilised lateritic soil building construction technology have to be based on strong foundation of indepth laboratory and field investigations of the given soils to arrive at formulating reliable standards, specifications, and codes of practices in relation to specific materials, nature of stabiliser, construction technology and operative local climatic conditions.

12.4.6 Formulation of mix-design and quality control of tropical soil stabilised products

Depending upon the purpose to which the stabilised soil is to be used there are a number of acceptance criteria of the final products. These include requirements and restrictions stipulated for the end-products in terms of volume stability, durability, strength and permeability (e.g. Ingles and Metcalf, 1972). The requirements for stabilised soils for pavement are of course more stringent than for stabilised blocks for walling. Apparently, there are various criteria for accepting or rejecting the soil for stabilisation for specific purposes. Similarly, because climatic conditions do influence the performance of stabilised soils for engineering purposes, specifications and standards for arid areas tend to be less stringent than those for the high rainfall wet regions.

From the above considerations, it appears obvious that dividing a country into specific climatic or moisture zones for the purpose of formulating standards and specifications for soil stabilised blocks building construction may help optimise the use of the stabiliser. From the viewpoint of soil types, long experiences all over the world have led to the development of empirical specifications relating the textural soil type, to the most suitable stabilisers, all other compositional factors being the same. For example, a loose generalisation like "clayey soils are best stabilised using lime while granular soils are more amenable to cement stabilisation" may be found in literature, but this should be qualified. Since some of the quality control tests are very laborious and time consuming, the tendency is to do more of the less expensive and time consuming tests and less of the more expensive ones.

If the various pedological soil systems of a country are mapped, and the basic compositional data defined these information can be grouped in terms of common environmental conditions of soil formation and evolution. In such cases, the mix-design found most suitable for a particular pedological soil system with specific compositional data will be found applicable to genetically (pedologically) similar soil systems of similar compositional data identified elsewhere. Here, then lies the valuable contribution of engineering pedology to soil stabilisation which was noted over 30 years ago by Wooltorton (Wooltorton, 1955); this was not taken seriously until recent developments in fundamental soil analysis and soil stabilisation studies in Australia and the United States have confirmed the inestimable value and the importance of the engineering pedology in soil stabilisation (Ingles and Metcalf, 1972; Mitchell, 1976; Mass. Inst. of Tech., 1952; Baver et al., 1972; Lambe, 1962; Gillot, 1968; Lea-dabrand et al., 1957; Yoder, 1957; Gidigasu, 1976). For a comprehensive discussion on the traditional temperate zone quality control of soil stabilised products and trial mix design evaluations for wall construction , the reader is referred to a valuable previous study (e.g. Fitzmaurice, 1958). The British Standards Institution (BSI), the American Society for Testing and Materials (ASTM), Association Francaise de Normalisation (AFNOR), Deutsch Industrie Norme (DIN), as well as Indian Standards Institution (ISI), have all formulated elaborate and comprehensive standards and specifications for soil stabilisation for various engineering construction purposes. These standards and specifications have been tailored to suit specific soil conditions of the various countries; it is just appropriate that tropical countries including Ghana also develop standards and specifications based upon local unique soil conditions using the locally available or potentially produceable local cementitious materials.

12.4.7 Quality control of soil-cement and soil-lime blocks

The chief properties of soil-based construction materials are volume stability, strength, durability and permeability (or moisture absorption). Under tropical conditions of rapid chemical weathering and deterioration of building matrials (e.g. Ranson, 1959), durability and erosion tests appear to be more relevant to the quality control of stabilised blocks than say strength test. Low durability leads to high maintenance costs without structural failure actually occurring. In stabilised soils, poor durability can result from many aspects of inferior mix-design, such as wrong choice of stabiliser, insufficient stabiliser or inadequate chemical or water resistance to weathering. A number of tests for assessing the strength and durability of soils and stabilizer soils have been proposed, but most of them are deficient; strength criteria has been established (Table 12.7). Because of this lack of significant test procedures, durability is one of the most difficult material evaluation problems the design engineer must face.

(a) Weathering/durability test

Studies in Ghana have established that so far as soil-cement block quality control is concerned the ASTM wetting and drying durability test (ASTM, 1958) is the most useful test and buildings put up with blocks checked using this test have performed satisfactorily since 1948 (40 years) and the well-maintained ones may even have another lifespan of another 20 to 30 years. In brief, the summary of the test is as follows: for every test and for every selected cement content, two specimens are prepared by compaction at optimum moisture content to maximum dry density. Both samples are cured for seven days before testing is begun. After curing, both samples are subjected to 12 cycles of alternative wetting and drying. At the end of each cycle, one specimen is vigorously brushed, using a standard procedure. Moisture and density determinations are made on the other unbrushed specimen during each test cycle. At the end of the test, the specimen are ovendried to constant weight, and the losses determined. Although the cement requirements are principally established on the basis of the results of the described durability tests, in some cases the compressive strengths of the test mixtures also are determined.

(b) **Volume stability**

Many clayey soils swell or shrink with change of their moisture content. These volume changes if uncontrolled, rapidly disrupt the produce and cause economic loss. Various methods and test procedures proposed for predicting the degree of potential volume change are given in various quality control of stabilised soil manuals, e.g. Fitzmaurice (1958).

(c) **Permeability and absorption**

Low permeability is desirable while high permeability associated with high potential for water absorption of blocks is undesirable. Specific tests have been designed to control this property or predict the degree to which it could manifest.

13.0 CONSTRUCTION OF LATERITIC MATERIALS EXPOSURE WALLS AT FUMESUA

13.1 INTRODUCTION

Four types of exposure walls are constructed at the Institute's exposure site at Fumesua (Kumasi). The type of walls constructed are:

1. Adobe block wall
2. Rammed earth wall
3. Lateritic stone block wall; and the
4. Local lime stabilised lateritic block wall.

With the adobe and the rammed earth walls and lime lateritic soil walls, concrete platforms were constructed to serve as the foundations. These concrete platforms may also be used later to train local masons as anticipated in the national follow-up action. The concrete platforms have measurements of about 3m long and 3m wide, with thicknesses of about 10cm.

13.2 CONSTRUCTION OF THE ADOBE EXPOSURE WALL

Two courses of sandcrete blocks measuring about 2m long and 2m wide at right angles by 1.75m were constructed with cement mortar. The wall was continued with 5 courses of the adobe blocks using clay soil-lime and cement-lime-sand mortars. The top was protected by covering it with aluminium roofing sheet against direct rainfall. The first two courses of sandcrete blocks were provided to check erosion due to rainfall and inadequate roof eaves. The wall was to be plastered with soil, sand 1:1 and 5% MC2 bitumen to make it impervious to water. After the construction of the walls it was observed that the lime-soil mortar showed some cracks at the joints. The cement-sand-lime mortar, however, showed no cracks; the joints appeared more attractive when the cement-lime-sand mortar was used. The construction process of the adobe wall is shown in Fig. 13.1.

13.3 CONSTRUCTION OF THE RAMMED EXPOSURE WALL

The rammed earth wall was also constructed on the concrete platform which served as the foundation. Similar to the case of the adobe wall, the rammed earth wall was constructed on two courses of erosion resistant sandcrete blocks, overlain by two courses of lime-soil blocks. A wooden formwork for the wall in the form of panels were manufactured and fixed in position as shown in Fig. 13.2. When it was firmly secured the formwork was filled with the prepared lateritic finegrained soil and rammed in stages of 0.3m lifts. The formwork was constructed in such a way that the height of the wall could be increased by just adding a 0.08m x 0.3m wawa (obeche) board to it. This process facilitated an easy compaction of the 0.3m lift walls through ramming. A wooden rammer was used to compact the soil. The wall of 2m by 2m by 1.75m was constructed. The next 0.6m thickness was compacted the following day. On the third day, it was decided that the formwork should be removed to find out if the wall could stand unsupported. When one side of the formwork and the ends were removed part of the wall collapsed. The remaining formwork was allowed to stay for sometime. When the other side of the formwork was removed after one week, the rammed earth was still damp as it was laid. This indicated that, without removing the formwork it could take a very long time to get the wall properly dried and adequate strength developed. It was observed that the rammed earth wall failed probably due to one or more of the following reasons:

(1) The material used was too gravelly and not enough fines to provide binding of the soil mix.

(2) The wall was not dry enough before the formwork was removed.

(3) The soil was moulded too dry; a wetter soil would be more workable since the technology is an improvement of Atakpame (pise) walling technology.

(4) This technology would be suitable for more clayey materials with little gravel size fraction to provide strengthening skeleton.

13.4 CONSTRUCTION OF LATERITIC STONE BLOCK EXPOSURE WALL

Lateritic stone boulders were used for raising an exposure wall since getting the bigger stones into block/brick sizes was fairly difficult. Because of the irregular nature of the boulders a lot of sand-cement or sand-lime mortars was used to raise this type of wall. The walls also have to be plastered to give them good appearance. To achieve better results the lateritic stones have to be cut into proper brick/block forms, hence the need to develop lateritic stone cutting machine. Hand cutting is not safe and it could be time consuming thus making the cost of the wall per unit area rather expensive. The foundation below the lateritic boulder exposure wall was crushed lateritic stone aggregate sand-cement mortar mixes. The standard 45.72cm foundation base dug to about 0.75m was filled to some thickness and the lateritic aggregate foundation was thinned to about 23cm at the ground level to receive the superstructure exposure wall. The main difficulty with the construction of the lateritic boulder exposure wall was in ensuring straight wall and the excessive amount of mortar that was used. However, in areas where they constitute the sole stony material they could be used confidently; scientific cutting of these stones into regular block for use with minimum mortar is a problem that has to be solved. A typical lateritic boulder exposure wall is shown in Fig.13.3. The irregularity is the key negative feature. The use of the boulders to protect the walls through pitching using sand-cement mortar or proper drainage near the wall is also illustrated.

13.5 CONSTRUCTION OF LATERITIC SOIL LOCAL LIME STABILISED BLOCK EXPOSURE WALL

Fairly good blocks were produced with the locally produced lime from local limestone and clam shells. Some of the limestone lime could be enriched with cement to help the development of adequate strength. The lime content in the soil was between 6 and 7% and the optimum moulding moisture content was around 20%. Generally, the blocks should be moulded far in excess of the optimum moisture content of standard Proctor optimum moisture content. The presence of experienced soil engineer, or concrete technologist, failing that good technicians in these fields can be very useful. The content of lime to achieve adequate strength development depends, to a great extent, on having well-graded fine-grained soils, either they are by nature or through blending two soils or even removing undesirable fractions from a particular lateritic material to improve the grading. The exposure walls have been constructed and their performance in relation to the moist sub-humid climatic zone is being monitored in accordance with the chart designed for the purpose (see Table 7.1).

14.0 CONSTRUCTION OF THE DEMONSTRATION BUILDINGS

14.1 INTRODUCTION

Based upon information collected from the literature, the field and at the exposure wall site at Fumesua, design and construction of the demonstration buildings were started; the first one was at Kokoben (near Kumasi). This is a two-bedroom house with the possibility of providing an extension of one bedroom in the future, kitchen, bath, toilet and a store . The project team met the chief and people of Kokoben and had discussions with them on the role that both parties were to play. The project team emphasised that IDRC's financial commitment per a demonstration building was the cedi equivalent of 2,500 Canadian dollars. This would go into the purchase of materials such as roofing sheets, cement, locks, wire nails, bitumen emulison for wall plasterings and technical supervision. The chief and people of Kokoben were to offer communal labour including some semi-skilled artisans work inputs. The chief and people of Kokoben also provided two trees of Albisia (Albisia ferruginea) which were felled and sawn through IDRC funding. The location of the proposed demonstration building was chosen in collaboration with the chief, the people, especially the Headteacher of the school in the village, since it was to be the residence of the Headteacher of the local Junior Secondary School. The site was surveyed by the project team. Foundation trenches were dug through communal labour by the volunteers and the people immediately started the production of the adobe blocks under the supervision of a project technician using the TEK block machine bought with IDRC funds. The Architect and the Building Construction Technician were constantly inter-acting with the people. Because it was a farming season, the people had to be divided into 5 groups with each group working for a day in the week while members of the other 4 groups went to their farms.

14.2 DESIGN CONCEPT OF THE RESIDENTIAL BUILDING AT KOKOBEN (MOIST SUB-HUMID ZONE)

The concept of design of the residential house at Kokoben was based on the climate and the traditional living habits of the people in the area. The climate is quite warm and so it is assumed that there will be much outside or outdoor living activities except when it is time to go to bed in the night. The two rooms mainly for sleeping activities are separated from the cooking and toilet facility areas and this creates a courtyard for outdoor living and at the same time privacy even if someone sits outside the rooms. The courtyard which separates the rooms from the cooking area also makes it more convenient for the use of firewood or charcoal in the kitchen without much damage to the structure as a whole. The simple straight line concept also makes it easy for future extension and also easy construction and maintenance. The ground floor plan of the building is shown in Fig.14.1.

14.3 UTILIZATION OF MATERIALS

Since it is in the rural area that these buildings are principally to be built, most of the materials to be used must be those fairly easily available to the rural people - that is, locally available lateritic materials. Other matrials were mass concrete and some sandcrete blocks. Cement or lime stabilized lateritic soil blocks or lateritic stone blocks were to be laid to about 0.3m to 0.5m above ground level. The superstructure walls would be laid using the non-stabilised lateritic soil adobe blocks produced from the mainly finegrained soils available at Kokoben. The roof framing materials were mainly wood, either sawn timber or treated or known durable woods. The only material for the roof framing which could not be obtained locally by the rural people would be binding wire for holding the roof framing members to the walls. The roof covering, however, was to be either asbestos sheets, galvanized iron sheets, aluminium sheets, clay tile, mud or thatch, whichever was most cheaply available having regard to the skilled manpower. In this particular case, there were no local skilled labour; they were provided from outside at a cost to IDRC funds. The door and window frames as well as door and window shutters were all in treated or durable timber. The use of non-reinforced concrete lintels over door and window openings helped to reduce cost and also made it easier for the people to build the house more easily. The floor finishes would be in various forms depending on available materials, either raw or local lime/cement treated. The typical floor screeding used for the Kokoben building is shown in Fig. 14.2.

14.4 CONSTRUCTION BY SELF-HELP APPROACH

The demonstration buildings were built by self-help method. Most of the materials were made available and the methods of material application were discussed with the skilled volunteers; tools needed are the usual walling tools used by masons (see

Appendix 8). In the self-help method/communal labour concept, all able-bodied members of the community - village or small town are organised as a co-operative group and they worked together in the production of the adobe blocks and the construction of the house. The organisation of the labour force and the interaction with the workers showed that it is an ideal technology transfer process through training for the nucleus rural community. The detailed aspects would, of course, vary from place to place but the principle will be the same. The technology of construction is imparted to the village craftsmen by the project team during the construction of each demonstration building. By bringing the people together, a mini co-operative society for self-help appeared to be in the making. The cost of the residential building or any community facility such as clinic and resource centre would be considerably reduced since there will be virtually little or no labour cost which now in Ghana appears to be as high as 30-40%. The definition of optimum manpower requirements for the construction of such buildings would have to be defined in each situation and generalized principles of organising building site and construction operations would be adapted to suit each new situation, depending especially upon the type of skilled and unskilled human resources available. The typical ventilated pit latrine used for the Kokoben building is shown in Fig. 14.3. During the construction of the residential building at Kokoben, the volunteers complained about the decision to build a residential building instead of a facility that most of the community would benefit from. In fact, when the electrification project execution reached Kokoben and volunteers were needed, the IDRC project was abandoned and only returned after the completion of the electrification project. The project team investigated the issue and a decision was taken that buildings that would serve the greatest part of the community should be considered for the other climatic zones. It was the intention of the project team to provide typical drawings of such facilities as rural clinic and resource centre, vocational training school, Junior Secondary School buildings, community centre, child care centre, and small places of worship, etc., that would be made available to rural communities. With the experience of Kokoben, it was decided that the buildings for the semi-arid and the dry sub-humid climatic zones should be rural clinic and resource centres. The locations for these facilities are Gambibigo (near Bolgatanga) (semi-arid climatic zone) and Poase Cement (dry sub-humid climatic zone). The facility for the wet climatic zone is to be a Day Care Centre in a rural community near Axim or Half Assini. The ground floor plan of the typical rural clinic and resource centre is shown in Fig.14.4. Since the most appropriate methods of planning, design and construction technologies are aimed at as long term target, some aspects of the components of the rural buildings have been singled out with areas of possible improvement or introduction of new technologies discussed. For example, the potential areas for cost saving and/or innovative designs and construction technologies are listed elsewhere (see Table 15.1).

14.5 PROTECTION OF EARTH BUILDING WALLS

One of the most important earth building problems in rural Ghana is the protection of earth walls with water-proof renderings. Houses are generally made of earths/soils which have very little natural durability and considerable damage is done to the houses during the rainy season. Walls could have been protected against rain by sufficient overhang of roofs but this is rarely done or when they are provided the overhang may become ineffective against driving rain or by application of mud-plasters without introducing into it any locally available water-proofing material such as cowdung or banana stem extract. These renderings are, no doubt, very cheap but require more research, constant maintenance and renewal almost every year.

In many developing countries, more and more people have tried to use sand cement plasters for earth buildings or lime wash. When sand cement plaster is used, most often, large slabs of plaster break off from the earth wall due to lack of sufficient bond between the weak wall material and the high strength cement plaster. Considerable research efforts to find alternative solutions to the earth wall protection problem have been made particularly in India (NBO, 1958) and the results reported have been of great value to earth building technologists throughout the developing world. For example, it is found during field studies that, plastering of relatively weak earth walls with fairly hard sand-cement mortars has caused many failures of the plaster due to the differential thermal properties of earth and sand-cement-water paste. The literature is replete with other useful alternative solutions for protecting and plastering earth walls (e.g. Mathur (undated); Bawa and Hornsby-Odoi (1965). Indeed, significant studies on various options have been undertaken at the Building and Road Research Institute. For example, (BRRI unpublished data; see Fig.6.5) some research results revealed failures of all earth based exposure walls except those plastered with relatively softer water-proofing materials over sand-cement mortars. One option that has proved to be most useful, cheap and effective was developed at the BRRI (CSIR) (Bawa and Hornsby-Odoi, 1965) and this has been successfully tried in the field by the Department of Planning and Housing Research of the University in Kumasi. The solution lies obviously in mixing soil and sand in various proportions and adding some amount of outback bitumen. Exposure walls protected with this technology have not cracked or sheared off and even no trace of erosion has been noted. Some exposure walls have been standing for over 20 years now. This technology was applied during the demonstration rural clinic and resource centre building construction at Gambibigo. The characteristics of the soils tested by Bawa and Hornsby-Odoi, 1965, and used with bitumen to formulate the different plaster specifications adopted with field performance records recorded are given in Fig. 14.5 and Table 14.1. Some of the conclusions drawn during previous studies at the Institute are as follows (Bawa and Hornsby-Odoi, 1965).

Earth walls plastered with bituminous mixtures are dark in colour and usually dull in appearance. It is, however, possible to improve the appearance by the application of not less than two coats of lime wash or cement paint. Cement paint of any colour may be used. The precaution to be taken for successful painting results is that the plaster should be allowed sufficient time to cure completely so that all volatile solvent in the bitumen is removed. In some environments it may require many weeks to completely drive out the solvent. If this precaution is not taken, it will result in dark oily patches on the painted surface.

Cement paint or lime wash will have another advantage of sealing the minute hair cracks which are usually developed in the plaster due to shrinkage on drying. It is now certain from the existing knowledge (e.g. Bawa and Hornsby-Odoi, 1965) that:

(a) Laboratory tests and semi-field trials have shown that durable waterproof plaster for earthwalls could be prepared by the addition of small amounts of bituminous material to suitable soils available locally. The recommended percentage of bituminous material may vary depending on the type of soil. As bulk densities of loose soil and bitumen are approximately the same, it does not make much difference whether bitumen is added by weight or by volume but addition by volume is more practicable.

(b) Addition of bitumen above five (5) per cent would seem to be more expensive while less than this amount may give weak and less durable plaster.

(c) Medium curing bituminous cutback MC2, which is easily available in most developing countries, is quite suitable for mixing with moist soil-sand mixtures.

(d) Rapid setting or quick breaking emulsion such as "Colas" is not suitable for mixing with soils. Instead any slow setting emulsion such as "Terolas" may be used if easily available but these emulsions are more expensive and contain less bitumen compared to cutback MC2

(e) Any soil can be used for making plaster provided its linear shrinkage is not high. If shrinkage is too much, the soil should be mixed with sand in such proportion that shrinkage cracks, as tested on a small patch of wall, are not wider than small hair cracks. Use of neat sand in making plaster is not recommended as it will yield somewhat porous plaster which may allow rain water to penetrate and soften the earth wall.

(f) Even topsoils containing organic matter or traces of roots may be employed without harmful effects.

(g) Incorporation of large quantities of straw in the soil-bitumen mixes to reduce shrinkage of plaster or cowdung for making it waterproof is very cumbersome and tedious and is not essential for successful application.

During inspection of walls in the field many interesting solutions worthy of further investigation were noted in the semi-arid climatic zone, where earth building construction technologies are very ingeneously demonstrated. Most of the successful soil plasters were treated; the secrets behind the success will have to be found later. However, a soil type without any local stabilisation method was found to give very satisfactory result, the grading curve of this lateritic soil is shown in Fig. 14.6.

The completed Kokoben building which will be the residence of the Headteacher of the local Junior Secondary School is shown in Fig.14.7. The completed rural clinic and resource centre at Gambibigo is also shown in Fig. 14.8. Due to disturbances from the rains and less enthusiasm for communal labour, the Poase Cement project is yet to be completed. The project architect visited the village in March, 1993, to inspect the number of blocks moulded and to also do the setting out of the building for them. There is a Roman Catholic vocational school at Poase Cement where the boys specialise in brick/block moulding and brick laying, and we were assured by the Headmaster, Mr. Gbokuku, that the students will assist to improve the quality of the work. Building materials worth about C1.2m had been sent and receipt of the materials was confirmed as easly as 6th March, 1992. Due to price fluctuations and increase in the cost of foreign buiding materials, the fourth project could not be started; the project team hopes to appproach the Minister, Ministry of Works and Housing, through the sector Minister of Science and Technology for assistance to construct the Day Care Centre in the wet climatic zone also. All the buildings will be subject to instrumentation to monitor the indoor climate to compare this with sandcrete block buildings on long term basis. The general performance of the buildings in the four climatic zones will also be subject to periodic evaluation in order to identify possible defects for improvement after investigation of the potential causes of the problems.

15.0 IMPROVING DESIGN AND CONSTRUCTION OF LOW-INCOME LATERITIC HOUSES IN GHANA

The traditional laterite housing technologies though appear to be very crude do illustrate some technical rudiments in them. This study would attempt to identify non-scientific practices and bring in technical inputs. Laterite houses have existed in many African countries for over 700 years and one sometimes wonders how possible it was to construct some of these structures, say in sub-saharan city of Timbuktu in Africa. However, we should not forget that the West African civilization strive mainly on in achievements in the field of architecture, earth building technology, trade and learning. Earthen housing construction, apparently has a long history in Africa. The research findings in this report are by no means new; they reflect attempts to introduce modern technological innovations into existing knowledge and traditional practices. In the tropics, environmental conditions do guide construction of good habitable laterite housing construction in the various climatic zones of the sub-saharan Africa. Indeed, in Africa, one cannot build low-cost houses with success without reference to the nature of local materials and the environmental climatic factors. In order to build scientifically, one has to take note of the rainfall conditions, temperature levels, and the relative humidity and their seasonal variations. For example, studies (Arulanandan et al, 1963) have shown that there is a close relationship between the rainfall and temperature patterns, and the vegetation zones. The climatic zones have therefore been defined taking into consideration all the climatic and environmental operative factors including altitude, direction of the prevailing wind, topography and surface soil type. Information in Table 5.1 has provided the basis for preparing the climatic map of Ghana using the so-called "Moisture Index Values" (e.g. Arulanandan et al., 1963). When designing for proper ventilation, the so-called wind roses or the main directions of the wind have to be considered. For example, Fig. 15.1, shows wind roses for Kumasi at midnight and at noon; similar information are available for Accra (coastal arid zones), and Tamale (northern arid zone); also available (Fig.15.2) are data for monthly and diurnal variations of wind speeds (Willis, 1962). The orientation of buildings vis-a-vis East-West and North-South directions are useful information for housing designers. Most architects do not take this factor into consideration when designing and constructing houses, the result is that sun rays are in the rooms the whole day. For example, Fig 15.3, shows that certain criteria need to be used vis-a-vis orientation of building relating to East-West directions in order to ensure that there is acceptable indoor climate for the dwellers. Fig.15.3 also shows how wind direction can be useful to ensure natural through ventilation in design. It is illustrated that we need to have the advantage of East-West building orientations. It does also give an indication as to the desired distance between two adjacent houses. Fig. 15.4 shows that building in depressions have a lot of drainage and ventilation problems; the ideal situations are hill tops with ample wind flow to ensure good ventilation. Wind brakes should, however, be provided to protect the buildings. The building designers or real estate developers of large-scale settlement schemes should also consider inter-group building ventilation and privacy of people living in the buildings. For example, Fig. 15.5a, is a poor arrangement of group buildings or blocks of flats, while Fig. 15.5b, shows desirable good housing planning, design and construction practice in the implementation of group building projects.

15.1 FOUNDATION FOR TROPICAL BUILDINGS

Foundation engineering is concerned with twin problems of evaluating the ability of the earth to support the loads and designing the proper transitional, particularly of drawing the super structure load into the ground (see Sowers, 1962). It has been established that there are three basic requirements of foundations as follows:

(1) The foundation structure must be properly located with respect to any future influence which could adversely affect its performance.

(2) The foundation (including the earth beneath) must be stable or safe from failure.

(3) The foundation must not settle or deflect sufficiently to damage the structure or impair its usefulness.

Good foundation practice requires the services of seasonal soil and foundation engineers in housing project execution.

15.2 LATERITE SOIL PROFILE AND FOUNDATION ENGINEERING PRACTICE

Provided erosion does not rapidly remove materials from the site, insitu weathering processes tend to develop a sequence of horizons within the zone of alteration. These horizons may grade abruptly from one to the next or be hard to distinguish. Their thicknesses may range from a few centimetres to several metres. The horizons may show difference in any or all of the following features:

(a) Degree of weathering

(b) Thickness of the various horizons

(c) Colour of the materials in the main horizons.

One important aspect of foundation design is the definition of depth of placement of foundation base, and this requires the definition of the following situations:

(a) Underground defects such as faults, soft layers, sinkholes, etc.

(b) Depth of large roots

(c) Depth of groundwater table and aggresiveness of the water.

(d) Depth of seasonal moisture and temperature variations (i.e. depth of potential zone of soil desiccation and dehydration).

(e) Depth of surfacial seasonal variations of soil bearing strength, compressibility and swell pressure in relation to environmental controls.

(f) Scour, erosion and undermining river currents as well as wind and wave action situations.

The characteristics of special soil conditions for placement of foundations are taken into consideration in relation to the following eight (8) factors of the site:

(a) Geological conditions especially the rock types and their chemical and primary mineral compositions.

(b) Geomorphological and terrain features including internal drainage conditions.

(c) Pedogenetic characteristics (profile features, structure and compositional factors) of the soil system.

(d) Degree of weathering, soil evolution trend and final soil type.

(e) Climatic conditions, especially sub-soil moisture conditions and seasonal variations with depth.

(f) Type and contents of primary and secondary minerals and chemical constituents.

(g) Degree of variability of genetic, compositional and geo-technical characteristics of the soils.

In practical terms, one should have some idea about the depth of weathering in a given region (e.g. Fig. 15.6); one should also have an idea about the variations of soil profile and the nature of subsoil, as well as the characteristics of the various horizons of the soil profile (Fig. 15.7). When these have been established, we should know the type of soil we are dealing with at the foundation base level. Among the laterite and other tropical residual soils there are some soils which are problematic and some criteria are given elsewhere (see Figs. 8.8 to 8.18) which help to identify the type of problem soils we are dealing with.

Another important factor that has to be considered is the depth of seasonal temperature variation (Fig. 15.8). There is also the zone of moisture variations and desiccation, inducing variations in soil properties such as moisture content, density, linear shrinkage (Figs. 15.9-15.11) and unless the foundation base is placed below these zones of temperature, morphological and soil property variations, there may be trouble with the long-term stability the foundation and the buildings. A typical example of seasonal moisture variations with depth in a particular area, and generalised to Fig. 15.12. These information assist to identify the depth of safe placement of foundation base to avoid some of the problems associated with seasonal moisture variations. This depth for shallow foundation varies from 0.3m to 1m deep from the ground surface in most parts of Ghana. For safe sites, standard strip foundation (Fig. 15.13 and 15.14) is adequate. However, in problem situations other solution options have to be resorted to. One will realise that since water is the greatest destroyer of soil strength, foundation soil protection against strength loss and erosion is very important in laterite housing construction. Fig. 15.15 gives some typical details of foundation (shallow) constructions which are applicable to specific subsoil situations. Note that (see Fig. 15.14) where a foundation is stepped the width should be at least twice thickness and it should never be less than 0.3 metre. Shallow foundation design and construction in the various tropical countries have been reviewed by many authors including Wolfskill (undated); Schrekenbach and Abankwa (1983); Hammond (1984); Gidigasu (1977, 1985); Gidigasu and Andoh (1980); Gidigasu and Appeagyei (1984). Some of the best solutions to shallow foundation problems for tropical buildings that have given satisfactory services for specific soil conditions are reported elsewhere (e.g. Hammond, 1984). Water is the greatest danger to the stability of shallow foundations, and attempts have been made to find solutions to specific cases. For example, Fig. 15.16 show the various means by which the water can enter the subsoils and foundation structure itself to undermine the building. Various attempts have been made to deal with the problems of this nature (e.g. Tomlinson, 1986). An example of a suitable solution to such a problem to prevent, say floor damping is given in Fig. 15.17. Some areas where expansive soils overlay the site, a peculiar failure of buildings by the process of so-called corners down (Fig. 15.18) do occur. For such subsoil conditions specific foundation types are used; these have been reviewed elsewhere (Gidigasu, 1985, 1987, 1990) (see Fig. 15.15).

15.2 THE ADOBE WALLING TECHNOLOGIES

This technology of earth walling is fast catching on for some years now and it has proved successful provided regular maintenance is carried out on the building. If the wall is plastered and the effect of erosion is controlled around the building the house could render useful service for a very long time. Adobe walls made of blocks from the TEK block machine appears to be the one with the greatest potential becuase of ease of manufacture and of laying. The TEK Block Press would have to be mass produced to facilitate the production of durable adobe blocks and also make them affordable to rural housing societies, the same applies to lime-stabilised lateritic block walling.

15.3 THE RAMMED EARTH CONSTRUCTION TECHNOLOGY

This technology could produce very good walls for houses provided the right material is used for the construction. One factor which would limit its use in the rural areas is the construction of the shutterings for the walls. Technology inputs could assist in training carpenters to manufcture the shutterings. It was also found that it could be expensive and also needed skilled labour to do it; training would help eliminate these constraints.

15.4 EFFECT OF MOULDING MOISTURE ON THE STABILITY OF THE ADOBE AND RAMMED EARTH WALLS

Moulding moisture has a significant effect on the stability of the rammed earth. During the construction of the trial rammed earth wall, it was observed that when the moisture content was not adequate, good compaction was not achieved and when the moisture content was too much adequate compaction was also not achieved. Actually, when the soil is wet the ramming becomes very difficult. This indicates that for every soil type to be used, trial mouldings should be done to find out the appropriate moisture content for ramming which, in this case, was found to be about 5% wet of the optimum moisture content, of standard Proctor compaction.

15.5 EFFECT OF COMPOSITIONAL FACTORS ON THE QUALITY OF THE RAMMED EARTH

With the rammed earth wall constructed at Fumesua, it was observed that the soil composition affected the quality and stability of the wall. For example, micaceous soils appear to be unsuitable in untreated form for walling unless plastering is applied immediately. The gravel content should be related to wall thickness; generally gravel particles readily regregated in the wall. Based upon these observations optimum grading envelope should be proposed for lateritic materials in relation to the proposed thickness of the rammed earth wall.

15.6 COMPARISON BETWEEN RAMMED EARTH AND THE ATAKPAME WALLING TECHNOLOGY

With the rammed earth technology, it was found that the construction of the suttering needed skilled personnel and it could also be costly and the process more tedious than the Atakpame one. The Atakpame walling technology which has been in use for a very long time, does not require skilled labour and the process is very easy for anyone interested, whether skilled or not to adopt. With the high cost of building materials, the Atakpame technology would still have to be the one to be preferred by the rural people but improvement in the quality of the end-product would be desirable, this may form the subject of further developmental studies to be reported in the Third Technical Report early 1992.

The key aspect of the project is the production of durable, affordable and acceptable dwelling houses for the rural poor in West Africa including Ghana. The design of the buildings is therefore a very challenging task and care is to be taken to eliminate all existing faulty and uneconomic design methods and construction technologies. The architect has to draw on existing information on the good performance of earth buildings in West Africa and the vast literature published elsewhere (e.g. GTZ; Habitat and Cratterre). For example, special attention has to be taken of design and construction innovations to ensure that the proposed buildings are safe from the following known results of poor designs, construction and maintenance practices.

(1) Cracking of the earth adobe or rammed earth walls, due to poor soil selection, poor foundation type and poor construction technology.

(2) Weathering and spilling off of plasters and walls themselves, should be designed for.

(3) Foundation exposure through erosion due to lack of aprons around the buildings, should be designed for.

(4) Various options of lintels to replace the expensive reinforced concrete ones should be investigated.

(5) Proper roof design to provide adequate eaves and yet ensure appropriate hooking of the roof system to the wall to withstand the forces of driving rain and strong winds.

(6) Landscaping around the building to eliminate excessive compound erosion and creation of gulleys along village streets.

(7) Use of alternative secondary (non-exportable) species of timber to bring the roofing, door and window prices down to the affordable level for the rural poor.

(8) Poor indoor climatic and ventilation conditions as well as poor drainage and unhygienic conditions around the buildings to be avoided, through proper ventilation and building orientation.

Some of the possible solution options to the above-named problems are summarised in Table 15.1

15.7 SOME PROPOSALS FOR IMPROVING EARTH BUILDING DESIGNS AND CONSTRUCTION TECHNOLOGIES IN GHANA

The overall performance of earth buildings depend upon a number of factors. The field performance studies have attempted to isolate and handle the various components of the buildings, examine their performance and then attempt to propose improvements that will enhance the earth building construction technologies in Ghana. Because there has not been deliberate scientific input into earth building construction in Ghana, a lot of the earth buildings were wrongly constructed. For the purpose of clarity we will deal with the various building components separately.

15.7.1 Standard shallow foundations

For sound shallow foundation practice cognisance should be taken of the adverse effects of the environmental factors including the nature of the soil profile, the degree of desiccation of the soil, the depth of seasonal temperature and moisture variations in the profile, and the various means by which rain water enters subsoil below the foundation, and the foundation structure itself. Generally, it is desirable that the sub-soil conditions should be thoroughly evaluated geotechnically and depth of seasonal moisture and temperature variations well defined. Profile features should be properly characterised since non-uniformity of the soil beneath the foundation could lead to many foundation problems. Sometimes it is impossible to avoid areas underlain by problem soils such as dispersive and erodible soils, expansive and shrinkable soils, collapsible soils, and structurally sensitive soils. The relationship between shrinkage and volume change is sometimes indicative of poor materials for adobe block production. The degree of lateritization, the physico-chemical properties as well as the chemistry and mineralogy of the soils are important indicators. For example, the variability of the soil composition as well as the moisture and strength properties with depth are important indicators and so are the influence of certain compositional factors on the strength index of the soil in question. This aspect of site assessment falls within the competence of the soils and foundation engineers and hence justifies the participation in such a project of a versatile soils and foundation engineer who has profound knowledge of the soil types in the area.

The traditional shallow foundation would be recommended in good sub-soil areas; the general requirement is that the base of the foundation should be placed below the zone of seasonal variations of temperate, moisture, density, volume changes, and other significant poor soil properties. Where the site is rather difficult alternative foundation types may be resorted to. One option is to design gravity foundation to keep the swell pressure under control. Sometimes piles may be used. The float mat foundation type would be considered too expensive for low cost-houses since traditionally, it is constructed in reinforced concrete. For very poor sites the whole soils below the foundation of the building may have to be removed and replaced with rubble and lateritic gravels with lean concrete put on it; quartzitic gravels may also be used as fill material and well compacted.

15.7.2 Earth/earth based wall

The investigation has established that both raw as well as local lime stabilised lateritic fine-grained soils can be used to produce good adobe walling blocks. It has also been established that lateritic stone can be cut into proper block sizes for walling purposes. Good knowledge of the nature of the rock is required to be able to characterise them and select the most appropriate methods of winning of the stones into blocks; this falls within the area of engineering geologists. It is a good practice to select the most appropriate soil for raw or stabilised adobe walling blocks. This falls within the competence of a materials engineer; the skill of walling is an important process; this should be carried out under the supervision of a construction engineer or a competent construction technician. It is not possible to give specific instructions relating to the soil selection and/or improvement for adobe blocks production for all lateritic materials for walling constructional works. Each material should be subject to some preliminary evaluation since the wall quality will depend on the materials available; and the materials engineer should be well informed of how to deal with the materials in order to reduce cost.

15.7.3 Earth wall protection technologies

The problem of protecting earth building walls can be solved either through application of water-proof plastering materials such as bitumen, loamy sand mix, or use of more durable materials such as sandcrete blocks at the base to a certain height to eliminate potential erosional effects at the base of the wall or again, use specific technology of soil protection that have been developed in, say, India and North America. For example, blending of specific type of soil with bitumen have been found successful in Ghana, and the soil type that proved useful with bitumen as well as the technology of blending them with bitumen have been discussed in detail elsewhere (e.g. Bawa and Hornsby-Odoi, 1965). There are other technologies developed in various parts of the world not excluding Ghana. The improvement of these technologies have not been documented in detail and most of the technologies are not amenable to application in all environments with the human skills available. One major problem with wall protection is spilling off of cement plasters from earth walls. It is a technological error to assume that two materials of such different strengths can work together. The strength of the walling material, the mortar and the plastering material should be as close as possible to ensure compatibility. Strength ratios of the stronger to the weaker materials should be below 5. It has been found, for example, that where clayey soil mortar was used for laying unstabilised adobe blocks and the wall plastered with silty clay materials which are not amenable to dry cracking followed by two to three coats wash with bitumen to a certain height that is prone to attack by driving rain there had been good performance results. The problem of earth wall protection falls within the area of materials engineer; there is need for more research to give this problem some long-term solution.

15.7.4 Roof failures

We are always very surprised that driving rainstorms rip off some of our roofing sheets but we forget that because of lack of scientific inputs, for example, the concept of life expectancy roofing sheets is alien to us. We also ignorantly assume that all roofing sheets should last for, say, 100 years under all climatic and natural disaster prone conditions. Corrosion of roofing nails and sheets and other defective design practices such as inadequate roof slopes induce suction rather than load pressure and these cause roof failures. Another important consideration which desires looking into is the fact that excessive exploitation of our forest, which formerly served as wind brakes near rural houses are gone; tree planting to form wind brakes should be intensified to save rural dwellings from premature failures.

15.7.5 Erosion control of compounds and proper drainage

The traditional method of maintaining grounds in the rural areas is regular sweeping. In actual fact, it is a contribution to compound erosion. There are big gulleys in a lot of old settlements and some foundations are hanging about 2 metres from the initial level. In some cases, it is noted that there haved been no foundations at all. All said and done, it is suggested that there is need for scientific rural housing delivery process through adequate skilled manpower development and there is the need to induce local professionals especially architects, construction, materials, foundation and structural engineers, as well as landscape planners and designers to team up to produce durable and affordable rural buildings that will have life expectancy of, at least, 50 years. Proper drainage should form part of our rural settlement development strategy; site and service facilities may equally be provided as part of rural settlements development and sanitation improvement processes.

This project is, by no means, a housing project per se; it is a project on housing material development but housing material development cannot be handled in isolation, its role in the overall housing delivery process should have been kept in mind hence the lengthy interest in other aspects of the rural lateritic materials housing delivery strategies.

16.0 ECONOMICS OF USING NATURAL AND IMPROVED LATERITIC MATERIALS FOR RURAL HOUSING CONSTRUCTION

This chapter attempts to find an analytical justification for the promotion of earth building materials of acceptable quality at affordable price to respond to the construction needs of the country's population. It is an attempt to look at the building economics aspects of the general terms of reference.

Cost comparison of the five (5) walling material types namely, sandcrete, cement/laterite, raw laterite, lime laterite and rammed earth walling, building unit area of different wall types, unit cost of standard 18" x 9" x 6" the five (5) under-mentioned walling types. Similarly, the effect of transportation on unit block cost and total cost was investigated.

16.1 ECONOMC ANALYSIS AND METHODOLOGY

The analysis considered a standard 2-bedroom house as the experimental unit. For the purpose of this report, the walling element was isolated and emphasis placed on it. Sandcrete block wall which is fast becoming the conventional material for formal construction and laterite was compared in terms of cost differentials.

The quantities used in the analysis were based on the standard of measurement for building works (Smm 6). The attached summary bill of quantities were priced using basic prices of materials at Kumasi as at December, 1992.

e.g. Calculation of Cost/SY of Sandcrete Blockwork

i.	150mm (6") 12 No. @ C167.46/blk	C 2,009.52
ii.	Wastage 5-1/2%	110.52
iii.	Cement mortar 0.4 CFT @ C1,000	400.00
iv.	Mason 3/4 hr @ C312/hr	234.37
v.	Labourer 1/2 hr @ C125/hr	62.50
vi.	Scaffolding and sundries	60.00
		C2,876.91

ASSUMPTIONS

1. Assuming an eight hour working day
2. Rate/Man-day of skilled artisan ¢2,000/day
3. Labourer rate ¢1,000/day

SUMMARY OF COST/SY OF DIFFERENT WALLING MATERIALS

	Material type	Cost/SY) (¢)	Cost/SY ($)	Cost of nominal
1.	Sandcrete block	2,876,910	5.53	167.46
2.	Cement laterite block	1,516.34	2.916	51.99
3.	Raw laterite block	1,449.88	2.79	54.77
4.	Lime laterite block	1,547.74	2.977	62.47
5.	Rammed earth wall	1,009.96	2.112	27.10

1 US$ = C520 as at December, 1992

16.2 DETERMINATION OF UNIT PRICES OF STANDARD/NOMINAL SIZE OF WALLING BLOCK 457mm x 225mm x 150mm OF DIFFERING WALLING MATERIALS

(A) Conventional Sandcrete Block

<u>Analysis</u>

Material Inputs

i. Sand 6 CY/trip (bucket size) @ ¢7,000/trip = C7,000.00

No. of blocks derived using/assuming

Bulkage factor of 25%

Vol. per normal block = (1.5) (0.75) (0.5 = $\frac{6CY}{(0.21)\ CY}$. 0.75

= 214 No.

ii. From specification and by practice

3 bags of Portland cement = 100 blocks @ ¢2,900/bag = ¢ 8,700.00

for the derived 214 blocks equivalent cost = 18,618.00

iii. Water 3 barrels per trip @ C600/barrel ¢27,418.00

Labour

Moulding C30/block x 214 blocks ¢ 6,420.00

Plant

Sundry (conveyance) Pellets and machine ¢ 2,000.00

Summary

1.	Material	¢27,418.00
2.	Labour	6,420.00
3.	Plant	2,000.00

∴ Cost per block = $\frac{¢\ 35,838}{214\ blocks}$

= ¢167.46/block

(B) **Raw Laterite Soil**

a) **Material** ¢ 1,500.00

i. Laterite soil Winning

assumption Loading

	material very close to site, require one labourer for winning, loading, transportation @ C1,500/man-day	Transportation
ii.	Bonding agent (absence of cement or lime)	
iii.	Water 3 barrels @ ¢600/blocks	1,800.00
		¢ 3,300.00

b) **Labour**

Moulding ¢30/block x 214 blocks	¢ 6,420.00
	¢ 6,420.00

c) **Plant**

(Sundry) conveyance or press to site	¢ 2,000.00
	¢ 2,000.00

Summary

i.	Material	¢3,300.00	
ii.	Labour	6,420.00	
iii.	Plant	2,000.00	
			¢11,720.00

∴ Cost per laterite block = C11,720 / 214 blocks

= ¢54.77/block

(C) **Cement-laterite block**

a) **Material Inputs**

i.	Laterite soil (winning, loading, transportation)	¢ 1,500.00
ii.	Bonding Agent (4%-8%) assume 6% cement of (normal sandcrete block)	
iii.	Water 3 barrels @ ¢600/barrel	1,800.00
		¢ 4,417.80

b) **Labour**

Moulding ¢30/block x 214	¢ 6,420.00
	¢ 6,420.00

c) **Plant**

Sundry conveyance of block press, etc.	¢ 2,000.00
	¢ 2,000.00

Summary

i.	Material	¢ 4,417.80
ii.	Labour	6,420.00
iii.	Plant	2,000.00
		¢12,837.80

$$\frac{C12,837.80}{214}$$

∴ Cost per block = ¢ 159.99

(D) **Lime-laterite soil**

a) **Material Input**

i.	Laterite (winning, loading, transportation)		¢ 1,500.00
ii.	Bonding Agent		
	Cost of 15kg hydrated lime (BRRI)	= ¢ 1,200.00	
	Equivalent cost i.e. 50 kg cement	= 4,000.00	
	Equivalent quantity per trip of 6 CY	= 25,680.00	
	3%-6% lime composition assume 6%	= 1,648.80	
iii.	Water 3 barrels @ C600/ barrel	= 1,800.00	
		¢ 4,948.80	

b) **Labour**

Moulding C30/block x 214 ¢ 6,420.00

c) **Plant**

Conveyance ¢ 2,000.00

Summary

Material	=	¢ 4,948.80
Labour	=	6,420.00
Plant	=	2,000.00
Cost per block	=	¢13,368.80/214
	=	¢62.47/block

(E) **Rammed Earth**

a) **Material Input**

i.	Earth (winning, loading, transportation)	¢ 1,500.00
ii.	Bonding Agent	
iii.	Water for blocks 3 barrels @ C600/barrel	1,800.00
		¢ 3,300.00

b) **Labour**

Kneading -

c) **Plant** ¢ 2,500.00

Summary

Material	=	¢ 3,000.00		
Labour	=	2,500.00		
Plant	=	-		
			¢5,800.00	
Cost by equivalent volume	=		¢5,800/214	¢27.10

16.3 SAVINGS IN IMPORTED CEMENT

Statistics indicate that approximately 58 percent of all walling materials in Ghana is earth. Ghana being a developing country with competing demand for scarce materials, therefore, requires a housing strategy that will take its strength from the existing local resources. The existing housing stock have an average life spans of about forty years and therefore with the new improved laterite blocks, there is ample hope for improvement.

Below is the derived input equivalence of portland cement that will be employed in the conventional blockwall construction.

Item		Cost (¢)
1. Manufacturer of normal block 75 bags cement @ ¢2,900	=	¢217,500.00
2. Bonding mortar (1:4) cement and sand 25 bags at ¢2,900	=	72,500.00
Total cost of imported cement		¢290,000.00

The equivalent cost in US dollars (1 US $ = ¢520.00) is $557.69 per standard housing unit using the IDRC-BRRI experimental house Type A. With Ghana's current achieved delivery of 20,000 housing units per annum, this gives an estimated savings of approximately $11.15 million.

16.4 CONCLUSIONS

The cost analyses above showed that laterite blocks for house construction can serve as an alternative to the conventional sandcrete block wall construction. A two-bedroom house, e.g. IDRC-BRRI laterite housing experimental Type A costs

17.33% less than a similar one constructed with conventional sandcrete block as at December, 1992.

With the introduction of laterite block press and the adoption of high quality earth (laterite) for house construction, instead of the present dependence on sandcrete blocks, it is hoped a saving of approximately $11.15 million will be made annually based on current delivery rate of housing units. If the economic condition improves and the delivery rate is increased to the required delivery rate of 133,000 units annually, there will be a net saving of $74.17 million in scarce foreign money.

TABLE 16.1: TRANSPORTATIONAL VARIANCE

WALL TYPE	COST PER BLOCK TRANSPORTING					
A. Sandcrete Block Valuables	**167.46** <5km	**206.84** 5≤x<10	**211.24** 10≤x 15	**216.15** 15≤x 20	**218.50** 20≤x<25	**224** 25≤x<30
1. 6 CY of sand	7000	13500	13800	14200	14500	14700
2. Portland cement per bag	2900	3200	3300	3400	3400	3600
3. Conveyance of Pellets and Press	2000	4000	5000	6000	6500	7500
B. Cement laterite block	59.99	69.80	74.71	79.57	82.08	86.94
i. Portland cement per bag	2900	3200	3300	3400	3500	3600
ii. Conveyance of Pellets and Press	2000	4000	5000	6000	6500	7500
C. Laterite	54.77	64.11	68.78	73.45	75.79	80.47
i. Conveyance of Pellets and Press	2000	4000	5000	6000	6500	7500

TABLE 16.2: COST OF EACH TRADE SECTION (BILL ITEMS) AS A PROPORTION OF TOTAL COST OF BUILDING

ITEM	DESCRIPTION	LATERITE HOUSING	CONVEN-TIONAL SANDCRETE BLOCK	LATE-RITE	% COST OF EACH ITEM TRADI-TIONAL
A	Preliminaries	323,138	382.948	9.99	9.80
B	Substructure	829,379	1,043,070	25.00	26.66
C	Roofing	372,750	372,750	11.52	9.53
D	Blockwork	164,850	549,500	5.09	14.04
E	Woodwork	596,380	596,380	18.44	15.24
F	Wall, ceiling and floor finishing	376,280	376,280	11.63	9.60
G	Painting and Decorating	211,920	211,920	6.55	5.42
H	Services	200,000	200,000	6.18	5.11
I	External Works	180,000	180,000	5.60	4.60
	TOTAL	3,234,638	3,912,878	100%	100%

NOTE: The results represents cost pertaining to Kumasi, which lies in the middle belt of our country, Ghana.

TABLE 16.3: MARKET PRICE OF CEMENT IN VARIOUS LOCATIONS IN GHANA

LOCATION	DISTANCE FROM ACCRA (km)	PRICE FOR 50kg (bag C)
Accra	0	2,755
Kumasi	272	2,900
Takoradi	299	2,682
Koforidua	85	3,045
Tamale	654	4,350
Bolgatanga	815	4,350
Bawku	928	4,785

17.0 INSTITUTIONALISING THE RURAL LATERITIC HOUSING DELIVERY PROCESS IN GHANA

One of the main objectives of any Research and Development activities is to make the findings available to the user agencies. To achieve effective dissemination of research findings, practical application of the findings have to be organised through demonstration (practice) and education. Fig. 17.1 shows inter-relationships between the three areas. Fig. 17.2 also shows that in a generalised process of development of standards and specifications, the process has to involve eight phases. The four key ones being the research development and testing, the design specifications, building construction technology, and the in-service performance evaluation. Information gathered at various levels are used for assessing, evaluating and upgrading of existing standards, specifications, and technologies. This leads us to the concept of technology transfer. Technology transfer per se also involves eight stages or processes (Fig. 17.3). After the research execution all these processes have to be properly co-ordinated at the national and institutional levels, by policy instruments, researchers, institutions, extension officers, contractors, quality control specialists, as well as the beneficiacy target group. The central institution for dissemination of research findings and technology transfer relating to low cost housing in rural areas in Ghana is the Department of Rural Housing and Cottage Industries (DRHCI). Fig. 17.4 shows the existing structure of this department. The Department has been most ineffective due to many factors. The most negative factor is the typical top heavy structure with operational effectiveness in terms of outputs being insignificant at the project execution levels. The existing operational structure of the Department is presented in Fig. 17.5. Note a major weakness in the fact that the district organiser is not a professional, and also one does not seem to create room to relate the number of operatives at the lowest level to the magnitude of work. This may cause over work of the operatives where the project is a big one or redundancy where the project is small. Flexibility in this area is highly desirable. This Department is being decentralised to the 110 districts and the structure being proposed to enable it function effectively is shown in Fig. 17.6. With this structure, the DHRCI should become a co-ordinating institution with a free hand to tap resources from all institutions dealing with processes of materials research, development and production, utilization and field performance evaluation, as well as quality control technology in housing construction.

Quality control and development of local building materials should be the responsibility of accredited institutions such as the Building and Road Research Institute and similar institutions while the Department of Planning and Housing Research (UST) and the DRHCI should make themselves open to operate fully with other institutions as an agents of Technology Transfer to the grass-roots national, private and non-governmental infrastructural development organisations. There should be a follow up of action to train 200 masons after the seminar to be supported financially by the Ghana Government. The 200 masons will be brought to the BRRI from the various districts of Ghana to undergo a crash programme of training in earth building processes. As at now, there is no national institute in this country charged fully with the training of craftsmen in earth buildings construction. For example, Table 17.1 shows that earth construction is not even one of the courses being taught in all the state technical institutes and polytechnics of the Ghana Education Services. There is a strong need to expand existing institutional structures for training tradesmen in earth technologies for building construction. A proposal may be made by Government through the IDRC for consideration by CIDA, to develop follow-up actions that would ultimately lead to the setting up of a network of rural housing delivery facilities in the whole country. The existing local housing delivery institutions should set aside funds for continuous training of artisans in the skills of rural housing construction in earth. The Building and Road Research Institute in conjunction with all interested parties are ready to undertake the job of popularising earth technologies for building construction in Ghana.

17.1 NATIONAL HOUSING SITUATION

As indicated earlier, housing deficit as at 1986 for settlements with a population of 5,000 people and above was estimated at about 250,000 units. The overall demand for the next 20 years is 133,000 housing units per annum.

The Central Government provides about 20% of total urban housing and the private sector 80% of the housing delivery as at 1986. Since 1978, the cost of imported building materials and housing has been so phenomenal (Gidigasu, 1987a) that the average

Ghanaian is unable to put up his own house. The present housing crisis is due mainly to the lack of foreign exchange to import enough foreign building materials, and the general tendency on the part of past governments and local entrepreneurs to ignore the need to commercialize local research findings.

Now that the country is short of foreign exchange, and cannot continue to import foreign building materials to ensure large housing delivery to meet the deficit, the government is forced to start a vigorous programme of promoting the production and use of local building materials: stones, soil-based materials, and timber. The national housing projections to the year 2005 and proposed investments in various facilities to achieve the targets have been published by government (Ministry of Works and Housing, Ghana, 1986).

17.2 NATIONAL LOW-COST HOUSING PROGRAMME (1972-1974)

In 1972, a Committee was established by government as the most recent actor in the drive to provide housing within the means of large numbers of people. Dwelling units constructed with money provided to the committee generally consisted of one to four rooms and were situated on planned sites. Water and electrical power are generally available, and the sites have road access, latrines and storm drainage. Of 1,974 dwelling units either under construction or completed during Phase 1 of the project, all but 21 cost less than $US4,000.

All of the units planned during Phase 1 were to be located in the regional capitals. In addition to implementing low cost housing projects, the committee was also mandated to evolve an oranisational structure to facilitate the planning and implementation of national housing programmes and policies. Emphasis was to be placed on housing low-income Ghanaians and on utilizing local building materials wherever possible.

The problem over the years in achieving housing targets has been, among other things, the apparent disregard of the fact that the high cost of imported building materials is the main obstacle to cost reduction in housing. Secondly, the housing policies, if they existed at all, have been very ambiguous; because the mechanics for implementing the policies, programmes, and projects have not been clearly stated. Consequently, almost all the past housing programmes have had to be abandoned before the expiration of their planned period, due to financial and/or organizational bottlenecks. With the acute shortage of foreign currency to import sufficient foreign building materials, Ghana has no alternative but to develop local building materials using technologies and local resources with, of course, some foreign appropriate technological inputs.

17.3 PROPOSED ACTION PLAN FOR URBAN SLUM REHABILITATION AND UPGRADING

Slum areas in urban centres have over the years received very little attention. They are generally characterized by badly deteriorated housing conditions and infrastructure. These communities lack access roads, drainage, water supply, sanitation, etc. High population densities, coupled with limited or non-existent health facilities, expose the residents to high risk of disease and health hazards. The inhabitants of these areas possess a high degree of inventive genius which can be tapped to enhance productivity. Community upgrading schemes in urban and rural areas have been initiated in slum areas.

One successful scheme has revealed that subsequent schemes would consolidate benefits of the previous scheme as a cost-effective approach to improving the living environments of communities which are devoid of basic infrastructure services. It also underscores a rational approach to the role of the public sector in urban development through cost effective improvements to infrastructure such as roads, water, latrines and electricity. The programme constitutes an essential component of a proposed secondary cities project, designed through strengthening financial institutions of municipal administration to provide urban services and maintenance to enhance productivity.

The project will finance civil works, technical assistance, equipment, material and training for the provision of basic roads, drainage, water supply, electricity, sanitation and garbage disposal facilities in identified localities. The economic benefits (or costs) include increases in property values as a result of upgrading activities associated with neighbourhood improvements, as well as economic rates of return of over 500% within one year after completion of upgrading.

(a) The project is labour intensive and will therefore create employment opportunities to relieve unemployment.

(b) The project also addresses the problems of the urban poor through neighbourhood improvement programmes.

(c) Finally, the development of urban infrastructure will enhance the development of the economy.

17.4 RURAL HOUSING PROBLEMS

In rural areas, the 1986 statistics indicated that state housing delivery constitutes only 3%. In the 1975/76 to 1977/79 five-year development plan, urban and rural housing was allocated only 7.4% of the national budget, and of that amount, only a very small fraction was spent by government through the Department of Rural Housing and Cottage Industries. The Ministry of Labour and Social Welfare also tried to help the rural areas through self-help construction projects. These were mainly building construction works which were voluntarily undertaken by the rural community to improve their environment and to provide some amenities and facilities.

This was meant to minimize the dependence of rural communities on the central government for some of their developmental needs and also to build their competence and self reliability. For example, the 1975/76 programme of self-help construction projects included 27 rural school blocks, 3 community centres, one house-craft centre, one postal agency and one street, a total of 33 projects. Four of these projects were completed by the end of the financial year, with the rest at various stages of completion.

17.4.1 Scope of Proposed Rural Housing Activities

(a) Initiate programmes of assistance to rehabilitate rural houses.

(b) Initiate integrated rural housing development programmes with infrastructural services.

(c) Initiate rural industries as basis to generate economic activities and to reverse the rural-urban migration.

17.4.2 Infrastructure for Training Programme

(a) Human resource development through upgrading of skills of unskilled workers.

(b) Regional material laboratories to serve as training grounds for earth construction technicians in collaboration with the Research and Development institutes of the country.

(c) The existing 26 technical institutions under the Ghana Education Service that train building construction tradesmen do not have earth construction on their programmes - this vital area will have to be incorporated in their training programmes since that is the traditional housing technology.

(d) Retired or redeployed staff of housing delivery organisations may be mobilized to form the nucleus of a skilled manpower pool in the districts for undertaking housing construction works.

17.4.3 Levels of Human Resource Development Envisaged

(a) Training of tutors for Technical schools, Polytechnics and Junior Secondary Schools on earth (including stone) housing construction technologies.

(b) Training for managers of district building materials production centres.

(c) Training of construction operatives on-the-job after the Junior Secondary School or technical school programmes.

(d) Training of operatives for rural private contractors, rural housing societies and town/village development communities.

(e) Upgrading of skills from time to time through workshops, seminars and demonstration projects implementation schemes.

17.4.4 Technology Transfer

(a) The district training centres will be the focal point for the technology transfer from R & D institutes through training and demonstration housing project execution.

(b) There is the need to produce simple manuals on all aspects of rural housing and rehabilitation for the technical institutes, junior secondary schools and small-scale contractors.

17.4.5 Rehabilitation of Rural Houses

(a) This scheme has already started and is being supported by geotechnical, erosion control and foundation specialists.

(b) The district training centres will also provide upgrading courses for the operatives using relevant research institutions as their resource facilities.

17.4.6 Rural Housing Building Materials Development Programme

(a) Rural building materials development centres will be established in every district capital to produce building materials appropriate to the available raw materials of the district.

(b) In lateritic stone, sandstone and granite areas, stone housing technology is to be promoted. A UNIDO feasibility report for Ghana on the setting up of a stone technology unit attached to the Building and Road Research Institute

(Shadmon, 1975) will be updated and expanded for UNDP assistance in implementation.

(c) Where clays are abundant, small-scale brick factories are being set up with a revolving fund of 3-4 million cedis. This money will cover setting up, trial run and selling out of the factory to the District Council to recoup the money in order to carry out the same process in other districts with clay deposits on long term basis throughout the country.

(d) Where abundant limestone deposits and clam shells are available, cheap lime will be produced using small-scale rural technology (Ayetey and Gogo, 1975). In such areas, small-scale lime-soil stabilization factories will also be set up, and the stabilized blocks produced will be used for housing construction in the districts.

(e) In areas of abundant lateritic soils, adobe (pressed raw soil and air-dried brick) factories will be set up.

It is planned that the Rural Banks will support these projects.

17.5 IMPLEMENTATION OF RURAL HOUSING ACTION PLAN

The Department of Rural Housing and Cottage Industries is the main institution for co-ordinating all rural housing and rural housing/settlement rehabilitation and cottage industries projects in the country. Before it can take on its expanded responsibilities it should undergo extensive restructuring, strenthening, and decentralization to achieve effectiveness in operation.

17.5.1 Strengthening Process of the Department

(a) Action is being taken to set up district-level branches for building human and infrastructural resource cpability, particularly improvement of skills of the operatives and the supervisors.

(b) Encourage inter-disciplinary approach to the operation of the Department. For example, it will now liaise with the Town and Country Planning and other infrastructural development organisations. Regional infrastructural development agencies and materials laboratories and relevant private sector institutions will develop their district human capacity and resources to assist in improving the quality of life at the district levels.

Through this approach the Department will need among its district operatives and supervisors, the following key technicians:

Construction foreman

Survey (geodetic) assistant

Plumbing technician

Drainage technician

Health assistant

Water and Sewerage technician

Highway maintenance technician

These technicians would assist the department of rural housing in undertaking rural housing and general settlement rehabilitation works.

17.5.2 Supervisory Body at the District Level

The Department will be restructured, decentralized and strengthened to mobilize the following professional staff:

Building Technologist

Architect

Planner

Civil engineer

Economist

Representative of the district Rural Bank managers

Representative of the Department of Town and Country Planning

Specialist on land use and erosion control

Representative of Ghana Water and Severage Corporation

District Secretary or District Administrative Officer (as the Chairman)

17.5.3 Technology Transfer

The Building and Road Research Institute (CSIR), Department of Planning and Housing Research of the University of Science and Technology (UST), the Forestry Research Institute of Ghana (of the Forestry Commission) would make available to the Department their research findings and provide free consultancy services as well as train their operatives to ensure higher quality of work.

17.5.4 Financial Support for the District Level Operations

(a) Regular Government budgetary allocation through the Ministry of Works and Housing and Local Government.

(b) Cocoa Marketing Board which has been allocating some money for the rural roads and housing rehabilitation and street erosion control works in towns.

(c) Bank for Housing and Construction through rural banks.

(d) Rural communities will raise levies for improving their environments and for setting up small-scale industries.

(e) The Department of Rural Housing and Cottage Industries earn money through consultancy services; this money should be fed back into their operational fund to expand the scope of developmental activities.

(f) Foreign source of funding from say PAMSCAD, ILO, UNDP, etc. are anticipated.

17.6 PROMOTION OF COMMUNITY PARTICIPATION IN ENVIRONMENTAL IMPROVEMENTS

The general economic decline and poor financial conditions of the district councils have been the major factor for the deterioration in environmental conditions in many rural communities. Whereas the central government has been responsible for providing much of the sanitation and environmental improvement services in the past, it is now felt that community improvement should also be the responsibility of the community members. The decentralization process is also aimed at stimulating community interest in improving their environment. It is also designed to provide small tools/equipment to identifiable community groups to undertake community sanitation improvement, including street/drain/verge cleaning, waste collection, tree planting etc.

17.7 PROMOTION OF DEVELOPMENT AND USE OF LOCAL BUILDING CONSTRUCTION TOOLS

A major policy objective is to improve the plant holding of rural small-scale contractors in the informal sector in order to improve their performance. The decentralization process will provide financial assistance in upgrading skills and acquiring construction equipment for sale to selected trained contractors for their operations.

Project preparation will include identification of target contractors, assessment of needs, and preparation of project documents for implementation; this professional input will be provided by the district professional/research and development institutes as well as consultancy institutions at nominal fees or free.

17.8 SUMMARY AND CONCLUSIONS

Ghana attained independence in March, 1957, with high expectations based on the huge reserve of hard currency which she was earning as a leading cocoa producing country. She also had efficient infrastructure for gold and diamond mining, which added more foreign earnings. The taste of a small proportion of the population for foreign commodities, and their control of political and economic power, prevented rural development. Many capital-intensive industries based on imported raw materials were set up.

The neglect of rural development led systematically to the rural urban migration of potential cocoa farmers and neglect of cocoa production. This coupled with a drastic drop in cocoa price, resulted in the depletion of foreign exchange to buy spare parts for the mining industry and industrial complexes, and raw materials to feed the factories.

18.0 STRATEGIES FOR DEVELOPING NEW BUILDING MATERIALS IN GHANA

The Building Materials Laboratory of the Technical University of Denmark is reported to have developed a method of using lateritic finegrained soils as basic raw materials for the production of a very hard block called "Latorex", suitable for use in the high technology building construction industry. It is suggested that the colour of the most suitable laterite soils for the production of "Latorex" range from yellow to deep red. It is also reported that lateritic materials with 10-12% sand fraction content and 20 to 50% clay size content are ideal for "Latorex" production. Similar studies are being undertaken in some other European and North American countries through co-operative programmes with developing countries of Asia, Latin America and Africa. The United Nations Industrial Development Organisation (UNIDO) is also believed to be supporting a programme in Belgium to upgrade the durability of lateritic materials through low to high energy processes to produce high quality, durable, high bearing strength and non-erodible building materials. A staff of the Building and Road Research Institute has been involved in this programme and has proposed a highly innovative process of low energy stabilisation of typical lateritic soils from Ghana using alkaline additives. The doctorate Thesis produced (Gogo, 1990) has resulted from the joint research work undertaken in collaboration with the powerful composite materials development group at the Vrije Universiteit, Brussels. National support for and the commercialisation of this technology in Ghana is highly proposed. This work is considered a major breakthrough in low energy high technology materials development using lateritic soils as the basic raw materials. It is understood that similar studies are being undertaken to introduce walling bricks produced through mixing and pressing lateritic clays and loamy clays in especially designed presses developed in West Germany. The history of trying to promote this materials in Ghana is of the historical past.

These lateritic soil based materials are undergoing field trials in many developing countries but there is some fear in many quarters about the nature of the real chemical contents of some of these stabilisers; because dangerous toxin wastes to human being are suspected as possible elements incorporated in some of the stabilisers. The major research findings at the BRRI, namely the pozzolana-cement project should concern all of us in the national interest to ensure that it is commercialised.

In trying to achieve the aspirations of the Lagos Plan of Action, most African countries and International organisations are still unable to identify the most viable strategic choices for Africa to promote industrialisation at the shortest possible time. The Lagos Plan of Action has clearly defined the targets, strategies, but the choices may not be as simple as we might think. Recently, the International Development Research Centre (IDRC) of Canada hosted a workshop in Accra (IDRC, 1990) in conjunction with the Association of African Universities to identify the most advantageous strategic Research and Development (R & D) choices for top professional specialists, policy makers, university administrators, and researchers from the sub-Saharan Africa. It clearly brought out many interesting reasons to improve research development, remedies for low research capability, the need for increased research capability, Donor Assistance Policy, measures for the use of research results, strengthening National Research Development policies, as well as appropriate funding mechanisms. It seems that institutional strengthening and strengthening of research capability as well as the response of the recipient countries to the challenges of doing the greater part of the work themselves stand out as key bottlenecks or constraints that militate against making the desired impact in the field of R & D activities in the sub-region.

The private sector which is the most potential actor in buying, implementing and commercialising the R & D findings is at the moment too weak to play its dominant role as the key vehicle for rapid industrialization and economic growth. If we consider the eight classes of high technology materials used by society (Table 18.1), Africa has not caught up with the technology of producing any of them. The problem is definitely not associated with the inferior brain of Africans but that of inability to take the destiny of our economies in our own hands. Technical assistance and aids are helpful but they may not be forthcoming all the time. Indeed, most of the South-East Asian countries have achieved breakthroughs in various areas because they have always been aware that the growth and well-being in their subregion can only materialise first and foremost through their own efforts. The strong belief by some African countries that the economic growth in Africa can only come from outside the continent has been historically disproved because foreign aid is there but the situation is growing worse. It is said that "THE WISEMAN HAS HIS

The only way of reviving the economy is to give rural development priority, increase cocoa production (through a sound reward policy), diversify cash crop production, and, most importantly, mobilize the population, especially the rural people, through deliberate long-term action plans and implementation policies. This is being achieved through a policy of almost total decentralization in which the district councils would become the focal point of all the political and economic, especially agricultural and small-scale industrial development, activities.

The result anticipated is the reverse of rural-urban population migration, increased agricultural (including cocoa) production, diversification of cash crops and strengthening of district and rural level infrastructural institutions. The importance of grassroots agricultural and industrial capacity building to promote every aspect of socio-economic development of Ghana constitutes the innovative strategy which has begun to yield encouraging results.

The benefits of grassroots district and rural level resource mobilization and capacity building for agricultural and small-scale industrial development through well-conceived motivation, incentive and reward policy have now been recognized. In addition, through South-South linkages and co-operative arrangements, innovative tailoring and adaptation of imported strategies can be evolved to suit specific environmental and socio-economic circumstances. The positive results emerging within this short period have amply demonstrated the values of tailoring development strategies to meet local needs.

HAPPINESS UNDER HIS FEET BUT THE FOOL LOOKS FOR IT AT A DISTANCE". The prices of imported building materials will never come down to meet the pocket of an average African house builder. Why is this so? It is because the costs of producing them is increasingly becoming very high. In a recently published State of the Art Review of "Materials Technology, Knowledge, Matter, Energy and Development" which was issued by the United Nations Centre for Science and Technology for Development (UNCSTD, 1988), the trends in technological options, and stragegies of high technology building materials development and production were discussed. In an Executive Summary prepared by Dr. Trindade its then Chief Executive Director, the key issues discussed related to technologies, implications for development, capacity building and policy options. In an overview to this volume of Advance Technòlogy Alert System (ATAS) of the Materials Development Series, Prof. Hondros, Director of the Petten Establishment (Joint Research Centre, Commission for the European Communities) entitled "Materials: A perspective" also outlined the trends for high technology materials development in a very comprehensive way. He touched on awareness, the nature of materials, the pattern of future materials consumption, the potential of materials science and technology and materials development trends. For example, his conception of the relationship between the quantity of materials in a product and information content is illustrated in Fig. 18.1

This concept of heuristic model indicates the time-dependent movements in the quantity of material in a product and information content of the materials. Each point represents the centre of gravity of a given material and the vector is the trend for the future. THE IMPLICATION OF THIS ILLUSTRATION IS THAT IN GENERAL FUTURE, MATERIALS DEVELOPMENT WILL INVOLVE A GREATER DEGREE OF INFORMATION CONTENT OR A GREATER DEGREE OF INTELLECTUAL SOPHISTICATION FOR EACH UNIT OF THE MATERIAL. The information content can only be the result of the R & D activities. In Africa we talk a lot about the continent being endowed with natural resources, and recently we have started boasting about the number of Ph.D we have in our universities and R & D institutions in our various countries. It is erroneous to believe that abundant natural resources, and a host of highly qualified human resources alone would guarantee industrialisation, we need to develop appropriate capabilities to add values to the materials and to venture into the development of new ones to serve the society. The requirements, indeed, include national commitment to look at ourselves in the face and ask key questions as to what we want and how we hope to achieve them. The readiness to do the greater part of the problem solving ourselves rather than rely too much on outside help must not be overlooked.

In the light of the above, the key question is how can we make desired impacts in the development of low energy building construction materials to promote the housing delivery processes and hence solve the present acute housing shortage? What programmes do we hope to evolve as long term strategies for using the abundant local raw materials (Fig. 18.2) to produce new, stronger, durable and cheap building construction materials? A lot has to do with how far we support technological and industrial institutions, motivate the capable workers to put in their best and for the Government as well as the private sector to be willing and ready to adopt or use the research findings which may not reflect high technology features in the beginning but which, with application and user feedback information, improvements in quality may come about. The patience to do this is one of the key factors that policy makers have to look at and introduce some protection of local young industries from the powerful, highly sophisticated foreign industrial products and multinational trading companies.

Though considerable research findings have been published by the Council for Scientific and Industrial Research (CSIR), the researchers are always dismayed to see that the preference is to look out for foreign consultants and sometimes hurriedly adapted technologies which we are unable to maintain having regard to the level of our technological capabilities, which are by all means, quite different from our academic qualifications which we boast about a lot these days.

In the area of local earth based building materials development and production, some impacts in the area of popularisation of brick and tile industries have been made. Marketing is, however, still a problem and some of the factories have been closed down due to mismanagement and lack of capability to handle the technology. Though we may feel that some impact has been made in the brick and tile production sector (Fig. 18.3), lack of skilled brick-layers still makes brick buildings comparatively expensive. The situation is, however, changing when the training for brick moulders and layers was initiated and financially supported by the Ministry of Works kand Housing at the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR).

For the future R & D project formulation and funding in the field of building materials development and production, emphasis should be placed on and funding made available for the areas of national needs in the short-term basis to solve the pressing housing delivery problem. Some of the key raw materials and their potentials for utilisation to produce high quality building materials are summarised in Table 18.2. To make greater impacts in the R & D activities in the areas of the development and production of new and durable building materials, we need to familiarise ourselves with the desired philosophy of Research and Development in materials science (e.g. Rohatgi, 1988; Fig. 18.4). The key actors are the links between institutions, industry and government, structure of materials institutions, the role of the materials institutions and levels of North-South and South-South co-operations. The need for inter-disciplinary research and development structures is illustrated in Fig. 18.5. The key elements include the role of research and development and education and training. Under the role of research and development, Williams (1988) emphasised that major technological advances in new materials are characterised by:

(a) A high degree of scientific content and research intensity.

(b) Multi-disciplinary analysis.

(c) Several families of materials and composites competing for the same application.

(d) Simultaneous impact in several areas.

(e) Rapid changes and obsolescence.

This characterisation should go beyond the traditional conception of materials research being a part of mechanical and chemical engineering departments of universities. The recognition has now come for the need to bring together specialists in different disciplines to deal with technological developments in new materials.

Assuming that the necessary scientific facilities and equipment and general infrastructure are provided, the R & D centres should develop the capacity to (Williams, 1988)

(a) Advise in the acquisition of technologies related to new materials.

(b) Decide among different options for the same application.

(c) Innovate existing technologies.

(d) Generate new materials by relating desired properties with possible structures arising from different formulations and processing conditions.

The challenges which have been enumerated above involve the joint action by Government and all related institutions to promote harmonious co-operation and collaboration including the pooling of human resources and equipment facilities utilisation.

19. REFERENCES

Ahn, P.M., 1970. West African Soils. 3rd Edition, Oxford University Press, London, 332pp.

Aitchison, G.D., 1953. Soil morphology and foundation engineering. Proc. Intern. Conf. Soil Mech. Found. Eng., 3rd, Zurich, Vol.1, pp:3-7.

Aitchison, G.D., 1972. Problems of soil mechanics and construction on soft clays and structurally unstable soils. Proc. Intern. Conf. Soil Mech. Found. Eng., 8th, Moscow, Vol.3, pp:161-190.

Aitchison, G.D., 1973. Twenty-five years of application of soil survey principles in the practice of foundation engineering. Geoderma, 10: 99-112.

Alcock, A.E.S., 1958. Better earth building in the tropics. Corona, Eckistis, Vol.5, No.30, pp: 108-109.

American Society for Testing and Materials (ASTM), 1958. Wetting and drying tests for compacted soil-cement mixtures. ASTM Designation: D.559-57, ASTM Standards, Philadelphia, Part 4, pp:1176-1181.

Amoa-Mensah, K., 1988. Construction Cost Information: An evaluation of construction cost data situation in Ghana today. Paper presented at Quantity Surveying Division (Ghana) Workshop on "Trends in Quantity Surveying Practice in Ghana", Building & Road Res. Institute, Kumasi, Ghana, 15pp. (unpublished).

Amonoo-Neizer, K. and Owusu-Siaw, M.E., 1973. Production of bricks by hand moulding techniques. B.R.R.I., Kumasi, Special Report; 19pp.

Anon, 1985. Earth construction technologies appropriate to developing countries. Proc. Intern. Colloquium, Brussels, Dec. 10-12, 1984; 423pp.

Anonymous, 1958. Waterproof renderings of mud walls. National Building Organisation (NBO), New Delhi (unpublished).

Anonymous (Undated). Low cost self-help housing, GTZ, Germany, 152pp. (unpublished).

Ayetey, J.K., 1977. Clays and their evaluation for brick manufacture. Building & Road Res. Institute, Kumasi, Current Paper No.11, 22pp.

Ayetey, J.K. and Gogo, J.O., 1973. Lime production from typical carbonate deposits in Ghana. Building & Road Research Institute, Special Report SR/3, Kumasi, 82pp.

Arulanandan, K. and Tunbridge, A.D., 1969. The performance of soil-cement roads in Ghana. Spec. Sess. Lateritic Soils. Proc. Intern. Conf. Soil Mech. Found. Eng., 7th, Mexico, Vol.2; 181-190.

Arulanandan, K., Tunbridge, A.D. and Saffo, A.O., 1963. A climatological approach to the estimation of moisture [illegible] Ghana Journal of Science, Vol.3, No.1, pp:66-75.

Aitchison, G.D. and Richard, B.G., [illegible] of [illegible] Australia. [illegible]

Moisture Changes in soils Beneath covered Areas', G.D. Aitchison ed. (Butterworths:Aust.), pp:1840-232.

Aitchison, G.D. and Grant, K., 1967. A preliminary appraisal of the engineering significance of silcretes in Australia. Proc. Reg. Conf. Africa Soil Mech. Found. Eng., 4th, Cape Town, Vol.1; pp:53-56.

Amoa-Mensah, K., 1989. Management Improvement Manual for Small-Scale Construction firms in Ghana. Building & Road Research Institute (BRRI), Kumasi, Report SR/18, 166pp.

Arulanandan, K. and Bhatia, H.S., 1960. The formation and engineering properties of some Ghanaian soils. Ghana Road Res. Note, Public Works Dept., Accra, 5pp. (unpublished).

Asamoah, G.K., 1966. Soils of a new site for Research Institutes, Kumasi. Soil Research Institute of Academy of Sciences, Kumasi, Ghana, 36pp.

Ackroyd, L.W., 1960. Notes on crushing strength of some Western Nigerian concretionary gravels and their selection for use as building materials. Min. Transp., Ibadan, W. Nigeria, Tech. paper 6pp. (unpublished).

Ackroyd, L.W., 1963. The correlation between engineering and pedological classification systems in Western Nigeria and its implications. Proc. Reg. Conf. Africa S.M.F.E., 3rd, Salisbury, Vol.1, pp:115-118.

Ackroyd, L.W., 1967. Formation and properties of concretionary and non-concretionary soils in Western Nigeria. Proc. Reg. Conf. Africa S.M.F.E., 4th, Cape Town, Vol.1, pp:47-52.

AETFAT, 1959. Vegetation map of Africa. Oxford University Press, London.

Afele, L.K., 1976. Housing financing in rural Ghana. Building and Road Res. Institute, Kumasi, Ghana, 10pp.

Afele, L.K., 1986. Mutually guaranteed, quasi-barter mortgage financing mechanism for the homeless. Proc. CIB Congress, Sept., 1986, Washington, Vol.5, pp:1725-1733.

Akinmusuru, J.O. and Adebayo, I.O., 1981. Fibre-reinforced earth blocks. ASCE Construction Journal, Vol.107, No. CO3, pp:487-496.

Alexander, L.T. and Cady, J.O., 1962. Genesis and hardening of laterite in soils. US Dept. Agric., Tech. Bulletin 1252, 90pp.

Atterberg, A. 1911. Uber die physikalische Bodenuntersuchung und uber die plastizitat der Tone. Int.Mitt. Bodenk; 1:10-43.

Bawa, N.S. and Bartel-Konacka, E.T., 1964. Production and use of building lime in Ghana. Building & Road Res. Institute, Kumasi, Note No.77; 35pp.

Bawa, N.S., 1965. Use of hydraulic lime in building construction. Proc. 3rd Congress of the CIB, Copenhagen. Towards Industrialised Building. Group G: Materials Development; 66pp.

Bawa, N.S. and Abankwa, M., 1974. Manual on building materials in Ghana: Their availability and use. Building & Road Res. Institute, Kumasi. Technical Paper 2, 133pp.

Bawa, N.S. and Hornsby-Odoi, A.G., 1965. Water-proof plasters for mudwalls for rural housing. Building & Road Research Institute, Kumasi, Ghana, Research Note No.19, 22pp.

Bawa, N.S. and Gidigasu, M.D., 1965. Cement stabilised Ghanaian soils as potential low-cost building materials (Revised 1965 version). Building & Road Research Institute, Kumasi, Ghana, 18pp.

Bates, D.A., 1962. Geology of Ghana. In: J.B. Wills (editor). Agriculture and land use in Ghana. Oxford University Press, London, pp:88-126.

Beck, J., 1971. Design and construction of modified traditional Atakpame houses. Dept. of Planning & Housing Research, Univ. Sci. Tech., Kumasi, Ghana, 18pp.

Brandy, N.C. 1974. The nature and properties of soils. MacMillan Publishing Co. Inc., New York, 8th edition, 639pp.

Bhatia, H.S. and Hammond, A.A., 1970. Durability and strength properties of lateritic aggregates of Ghana. Building & Road Res. Institute (BRRI), Project Report, SM.9; 15pp.

Brammer, H., 1962. Ghana soils. In: J.B. Wills (editor). Agriculture and land use in Ghana. Oxford University Press, London, pp:88-126.

British Standards Institution, 1975. Methods of testing soil for civil engineering purposes. Brit. Std., 1377: 143pp.

Buchanan, F., 1807. A journey from Madras through the countries of Mysore, Canara and Malabar, 2nd East Indian Company, London, 143pp.

Building and Road Research Institute (Ghana) and Lyon Associates Inc., (USA), 1971. Laterite and lateritic soils and other problem soils of Africa. U.S. Agency for International Development, Project No. AID/CSD-2164, 289pp.

Building and Road Research Institute (BRRI), 1974a. Actions to achieve cost reduction in public construction sector. Housing Programme. Building & Road Res. Institute, Kumasi, Ghana, 35pp.

Building and Road Research Institute (BRRI), 1974b. Actions to achieve cost reduction in public construction sector, Vol.4, Construction Materials Manufacture. Building and Road Research Institute, Kumasi, Ghana, 82pp.

Building and Road Research Institute (BRRI), 1976. External rendered finishes, Building Digest 196, Garston, Britain.

Building and Road Research Institute (BRRI), 1977. A feasibility study of manufacture of Portland cement in Northern Ghana. Building & Road Res. Institute, Special Report, 27pp.

Bulman, J.N., 1972. Soil stabilisation in Africa. Proc. Conf. African Highway, 2nd Rabat, Morocco.

Bunting, B.T., 1965. The geography of soils. Aldine Publ. Co., Chicago, 1st edition, 313pp.

Bampo-Addo, A., Raman, K.V. and Mortland, M.M., 1968. Clay mineral status of some major soil series in Ghana. Soil Sci., Vol.107, No.2, pp:119-125.

Barelli, N. and Mellios, C.B., 1985. Soil-lime reactions: A comparison study between two Brazilian red soils. Proc. Intern. Conf. on Geomechanics in Tropical Lateritic and

Saprolitic soils. 1st, Brasilia (11-14 February, 1985), Vol.2, pp:271-281.

Baver, L.D., Gadner, W.H. and Gadner, W.R., 1972. Soil physics. John Wiley & Sons, 4th edition, New York, 498pp.

Bhatia, H.S., Gidigasu, M.D., and Hornsby-Odoi, A.G., 1970. Importance of soil profile in the engineering studies of laterite soils in Ghana. Building & Road Research Institute, Kumasi, Ghana, Project Report SM.8: 14pp.

Brand, E.W. and Phillipson, 1985. Sampling and testing of residual soils. A review of international practice. Scorpion Press, Hong Kong, 194pp.

Building and Road Research Institute (BRRI), 1964-1989. Institutional Communication.

Bulman, J.N., 1964. The engineering properties of three micaceous soils from Ghana. Brit. Road Res. Lab., Note 559, 13pp (unpublished).

Casagrande, A., 1948. Classification and identification of soils. Transactions, Am. Soc. Civ. Engrs., Vol.113 (with discussions) pp:901-991.

Cartnel, H.S.and Berch, A.O., 1958. Lime stabilisation of soils for use in road foundations in Northern Rhodesia. Dept. of Sci. and Ind. Res. (U.K.), Road Res. Lab., Overseas Bull. No.9.

Central Bureau of Statistics (Ghana), 1984. Population census of Ghana. Central Bureau of Statistics, Accra, Ghana, 114pp.

Chatterjee, A.K., 1975. Use of agricultural and industrial wastes in construction of low-cost houses. Building & Road Res. Institute, Kumasi, Ghana, Current Paper 17, 31pp.

Civil Engineering Codes of Practice Joint Committee, 1954. Foundations. Institution of Civil Engineers, Civil Engineering Code of Practice No.4, London.

Coad, J.R., 1979. Lime-stabilised soil building blocks. Building Research and Practice, Paris, March/April, pp:80-89.

Coleman, J.D., 1965. The mesurement of colour in relation tothe structural analysis of soil. Proc. Intern. Conf. S.M.F.E., 6th, Montreal, Vol.1, pp:26-30.

Coleman, J.D., Farrar, D.M. and Marsh, A.D., 1964. The moisture characteristics, composition and structural analysis of red clay from Nyeri, Kenya. Geotechnique, 14(3): 263

Coleman, J.A., 1974. Labour resources of Ghana. Paper presented at the conference on "Achievement of Cost Reducation in Public Construction", June, 1974, Building & Road Res. Institute, Kumasi; 13pp. (unpublished).

Clarke, G.R., 1957. The study of the soil in the field. Clarendon press, Oxford, 4th edition, 204pp.

Clare, K.A. and Cruchley, A.E., 1957. Laboratory experiments in stabilisation of clays with hydrated lime. Geotechnique Vol.7: 97-111.

Clerk, N.T., 1974. Management training for engineers and technologists in the construction industry. paper presented at the Conference on"Achievement of Cost Reducation in Public Construction", June, 1974. Building & Road Res. Institute, Kumasi, 12pp. (unpublished).

Cooper, G.G., 1936. The bauxites of the Gold Coast. Geol. Survey Dept., Ghana, Bull.7, 33pp.

Cross, A.H.B., 1973. Ceramic laboratory: Some regional clays of Ghana. Industrial Research Institute, Accra (Special Report): 51pp.

Cross, A.H.B., 1974. Clay refractories for Ghanaian industry. Industrial Research Institute, Accra (Special Report), 22p.

Croft, J.B., 1964. The processes involved in the lime stabilisation of soils. Proc. ARRB Conf. 2(2), pp.1169-1204.

Casagrande, A., 1932. Research on the Atterberg limits on soils. Public Roads, 13:121-130.

Castro, de., 1969. A swelling test for the study of lateritic soils. Spec. Sess. Lateritic soils; Proc. Intern. Conf. Soil Mech. Found. Eng., 7th, Mexico, Vol.1, pp:97-106.

Commonwealth Science Council (CSC), 1985. Local raw materials for housing construction - Africa. Commonwealth Science Council, Technical Publications Series No.218, Commonwealth Science Council, National Research Council, Uganda, 292pp.

Commonwealth Science Council (CSC), 1985. Local raw materials for housing construction in Africa. Commonwealth Science Council Technical Publication Series No.218, London, 292pp.

Cook, J.R. and Newill, D., 1988. The field description and identification of tropical residual soils. Proc. Intern. Conf. Geomechanics in tropical soils, Singapore, Vol.1, pp:3-10.

Craterre (Doat et al.), 1979. Construire en terre, Edition Alternatives, Montmartie, Collection Au Architecture, Paris, 287pp.

Craterre (Doat, P., Hays, A., Houben, H., Matuk, S. and Vitoux, F., 1979). Construction en terre, Edition Alternatives. Collection au Architexture, Craterre, Villafontaine, France, 287pp.

Craterre, 1989. Traite de construction en terre. L'encyclopedie de la construction en terre, Vol.1, Editions Parantheses, Craterre, Centre Simone Sigmoret, Ville Fontaine, France, 355pp.

Dansou, P.A., 1972. La terre stabilise: Materiaux pour la construction des maisons. Centre de la construction et du Logement a Cacavelli, Lome (Togo), 45pp.

Datta, K.L. and Dove, D.M. (undated). Development of walling techniques for low-cost and rural housing. Building and Road Res. Institute, Kumasi, 20pp.

Dawson, R.F., 1953. Movement of small houses on expansive clay soil. Proc. Intern. Conf. S.M.F.E., 3rd, Zurich, Vol.1, pp:346-357.

Dawson, R.F., 1956. Special factors in lime stabilisation, chemical and mechanical stabilisation. HRB Bull., 129pp

De Graft-Johnson, J.W.S., Bhatia, H.S. and Gidigasu, M.D., 1969. Engineering characteristics of the laterite gravels of Ghana. Proc. Spec. Session, Lateritic soils, VII, ICSMFE, Mexico, pp:117-128.

De Graft-Johnson, J.W.S., Bhatia, H.S. and Hammond, A.A., 1972. Laterite gravel evaluation for road construction. J.

Soil Mech. Found. Div., Am. Soc. Civil Engrs., 98 (SM11), pp:1245-1265.

De Graft-Johnson, J.W.S., Bhatia, H.S. and Gidigasu, M.D., 1967. The consolidation and swell characteristics of Accra mottled clays. Proc. Asian Reg. Conf. S.M.F.E., 3rd, Haifa, Israel, Vol.1, pp:75-80.

De Graft-Johnson, J.W.S., Bhatia, H.S. and Gidigasu, M.D., 1968. Engineering characterisation of lateritic residual clay of Ghana for earthdam construction. Proc. Symposium on Rock and Earthfill Dam, New Delhi, India, Vol.1, pp:94-107.

De Graft-Johnson, J.W.S., Bhatia, H.S. and Gidigasu, M.D., 1969. The strength characteristics of residual micaceous soils and their application to stability problems: Proceedings, Intern. Conf. S.M.F.E., 7th Mexico, Vol.1, pp:165.

D'Hoore, J.L., 1964. Soil map of Africa: Scale 1 to 5,000,000; explanatory monograph. Comm. for Tech. Co-op. in Africa: Publ.93, 205pp.

Department of Rural Housing and Cottage Industries (DRHCI) (Ghana), 1988. Personal communications.

Department of Social Welfare and Housing (Ghana), 1948. The Asawasi Housing Scheme: Building in stabilised laterite, Kumasi. Government Printing Press, Accra, 23pp.

Diamond, S. and Kinter, E.B., 1965. Mechanisms of soil-lime stabilization. Highway Res. Board, Record 92:83-95.

Donaldson, G.W., 1962. Foundation problems experienced in Africa. The CCTA Inter-African Housing Secretariat, Publ.81, 17pp.

Dowling, J.W.F., 1966. The occurrence of laterites in Northern Nigeria and their appearance in aerial photographs. Eng. Geol. 1(3), pp:221-233.

Duncan, N., 1970. Engineering geology and rock mechanics. Leonard Hill Publishers, London, Vol.1, 252pp.

Dunstan, I., 1987. Building materials standardisation: Materials and structures. Chapman and Hall, London, Vol.20, No.116, pp:83-84.

Dreyfus, J., 1952. Laterites. Rev. Ge. Routes Aerodromes, 22(245): 88-100.

Dudley, J.H., 1970. Review of collapsible soils. Journal Soil Mech. Found. Div., A.S.C.E., Vol.96, No.SM3, pp:925-947

Dumbleton, M.J., 1963. The clay mineralogy of some soils from Northern Borneo considered in relation to their origin and their properties as road making materials. Brit. Road Res. Lab., Note 282, 18pp. (unpublished).

Emerson, W.W., 1957. A classification of soil aggregates based on their coherence in water. Aust. J. Soil Res. Vol.5, pp:47-57.

Farrow, J.E., 1975. Alternative housing policies for Ghanaian cities. Building & Road Res. Institute, Kumasi, Current Report 9, 27pp.

Fathy, Hanan, 1980. Architecture for the poor. Architectural Record, pp(39).

Fermor, L.L., 1911. What is laterite? Geol. Mag. 5(8):453-462; 507-516; 559-566.

Fitzmaurice, R., 1958. Manual on stabilised soil for housing construction. United Nations, New York, 125pp.

Fuller, W.B. and Thompson, S.E., 1907. The laws of proportioning concrete. Transactions of the American Society of Civil Engineers, 59, pp:67-143; Discussions 144-172.

French Agency for Energy Management (Plan Construction), 1987. Raw earth construction: The French equipment, Craterre, Genoble, 81pp.

Ghana Government, 1977. An official handbook: Information Services Department, Accra, Ghana: 541pp.

Gogo, J.O., 1974. Production and marketing potential of lime in Ghana. OAU-Inter-African Symposium on Building Materials, Design and Construction, Cairo, Egypt. Building & Road Res. Institute (BRRI), Kumasi, Ghana, 30pp.

Gogo, J.O., 1990. Geological and geotechnical evaluation of latosols from Ghana, and their improvement for construction. Ph.D Thesis, Vrije Universiteit Brussel, Brussels, 209pp. (unpublished thesis).

German Appropriate Technology Exchange (GATE) (Undated). Low cost self-help housing. Eschborn, 152pp.

GATE (Undated). Low cost self-help housing. Techniques for Low-cost self-help housing, West Germany, 151pp.

Ghana Education Service, Ministry of Education, Technical Division, 1989. Personal communications.

Gibbs, H.J. and Holtz, W.G., 1956. Engineering properties of expansive clays. Transactions, Am.Soc. Civ. Engrs., Vol.121, pp:641-663.

Gillot, J.E., 1968. Clay in engineering geology. Elsevier, Amsterdam, 296pp.

Government of the Republic of Zaire, UNESCO, UNCHS (Habitat), CEBTP, 1987. Seminar on Housing for the greatest number. Intern. Year of Shelter for the Homeless, Kinshasa, Zaire, Nov. 20-Dec. 3rd, 1987., 279pp.

Government of Belgium and United Nations Centre for Human Settlements (UNCHS-Habitat), 1984. Proc. Symposium on Earth Construction Technologies Appropriate to Developing Countries, Brussels, 423pp.

Grant, K.A. and Aitchison, G.D., 1970. Engineering significance of silcrete and ferricrete in Australia. Eng. Geol., Amsterdam, Vol.4, No.3, pp:93-120.

Grant, K.A., 1974. Laterites, ferricretes, bauxites and silcretes. Proc. 2nd Intern. Cong. Assoc. Eng. Geol., Vol.4, pp:31.1-31.8.

Gidigasu, M.D., 1971a. Parameters for classification of fine-grained laterite soils of Ghana. Highway Res. Board, Washington D.C., Record 374, pp:57-79.

Gidigasu, M.D., 1971b. Importance of soil genesis in the engineering classification of Ghana soils. Eng. Geol., Amsterdam, Vol.5, pp:117-161.

Gidigasu, M.D., 1971c. A contribution to the study of physico-chemical implications of tropical weathering and laterisation: Geotechnical Engineering, Bangkok, Vol.2, No.2, pp:131-149.

Gidigasu, M.D., 1972. Mode of formation and geotechnical characteristics of laterite materials of Ghana in relation to soil-forming factors. Eng. Geol., Amsterdam, Vol.6 No.2, pp:79-150.

Gidigasu, M.D. and Yeboa, S.L., 1972. The significance of pre-testing preparations in evaluating index properties of laterite materials: Highway Research Board, Washington D.C., Record 405, pp:105-116.

Gidigasu, M.D., 1974. Some problems relating to identification of laterite soils for engineering purposes. Ghana Engineer, Vol.5, No.2, 1974; pp:23-42.

Gidigasu, M.D, 1974. Degree of weathering in the identification of laterite materials for engineering purposes. Engineering Geology, Amsterdam, Vol.8, pp:213-266.

Gidigasu, M.D., 1977. Foundation and design of structures on expansive clay soils. Ghana Engineer, Vol.8, Accra, pp:99-150.

Gidigasu, M.D., 1985. Shallow foundations in problem soils of Ghana. Building Research and Practice, Paris, Vol.13(3), 1985, pp:153-160.

Gidigasu, M.D. 1986. Building materials of tomorrow - A clue to Africa's housing problems. Indutech, Journal Min. of Industries, Science & Technology, Vol.1, pp:120-161.

Gidigasu, M.D. and Ocloo, J.K., 1986. Potential use of industrially produced timber building components for low-cost housing in Ghana. Intern. Jnl. Housing Science and its applications. Miami, U.S.A., Vol.10, No.3, pp:221-240.

Gidigasu, M.D., 1988. Capacity building for materials technology and development; experiences and case studies: Ghana. Advanced Technology Alert System (ATAS), United Nations Centre for Science and Technology for Development, New York, Bulletin 5, pp:110-114.

Gidigasu, M.D., 1976. Book: Laterite soil engineering. Elsevier, Amsterdam, 554pp.

Gidigasu, M.D., Hammond, A.A. and Gogo, J.K., (Technical Editors), 1980. Proceedings, Regional Conference, Africa S.M.F.E., 7th: Balkema Rotterdam - Accra, Vol.2, pp:883.

Gidigasu, M.D., 1985. Sampling and testing of residual soils in Ghana: In E.W. Brand and H.B. Philipson (editors); Sampling and testing of residual soils - a review of international practice, Scorpion Press, Hong Kong, pp:65-74.

Gidigasu, M.D. and Bhatia, H.S., 1971. The importance of soil profiles in the engineering studies of laterite soils. Proc. Reg. Conf., Africa, S.M.F.E., 5th, Luanda, Angola, Vol.1, pp:2-55 to 2-60.

Gidigasu, M.D. and Bani, S.K., 1973. Geotechnical characteristics of troublesome laterite materials. Proc. Intern. Conf. S.M.F.E.

Gidigasu, M.D., 1977. Identification of a bauxite-waste for engineering purposes. Specialty Session on "Geotechnical Engineering and Environmental Control". Proc.

Intern. Conf. S.M.F.E., 9th, Tokyo, Vol.1 V/5, pp:305-318.

Gidigasu, M.D., 1980a. Some problems relating to compaction control of problem soils. Proc. Reg. Conf. Africa S.M.F.E., 7th, Accra, Vol.2, pp:785-796.

Gidigasu, M.D., 1980b. Foundation on problem soils. General Report. Proc. Regional Conf. Africa S.M.F.E., 7th, Accra, Vol.2, pp:689-703.

Gidigasu, M.D., 1980c. Variability of particle size distribution of a red mud with different pretest preparation methods. Proc. Regional Conf. Africa S.M.F.E., 7th, Accra, Vol.1, pp:171-178.

Gidigasu, M.D., 1970d. Variability of geotechnical properties of subgrade soils in a residual profile over phyllite. Proc. Regional Conf. Africa S.M.F.E., 7th, Accra, Vol.1, pp:95-104.

Gidigasu, M.D., 1970e. Some contributions to tropical soils engineering in Ghana. "Special Lecture": Proc. Regional Conf. Africa S.M.F.E., 7th Accra, Vol.2, pp:508-626.

Gidigasu, M.D., 1980f. Notes on the potential use of crushed laterite rock for concrete aggregates. Proc. Reg. Conf. Africa S.M.F.E., 7th, Accra, Vol.1, pp:467-477.

Gidigasu, M.D. and Andoh, M.B., 1980. Broad regional evaluation of expansive soil conditions for shallow foundations in Ghana. Proc. Reg. Conf. Africa S.M.F.E., 7th, Accra, Vol.1, pp:235-251.

Gidigasu, M.D. and Appeagyei, E., 1980. Geotechnical evaluation of natural and treated black cotton clay for possible use for low-cost pavement. Proc. Reg. Conf. Africa S.M.F.E., 7th, Accra, Vol.1, pp:363-375.

Gidigasu, M.D. and Dogbey, J.L.K., 1980a. Importance of strength criterion in selecting some residual gravels for pavement construction. Proc. Reg. Conf. Africa S.M.F.E., 7th, Accra, Vol.1, pp:317-330.

Gidigasu, M.D. and Dogbey, J.L.K., 1980b. Geotechnical characterisation of lateritised decomposed rocks for pavement construction in a dry semi-humid environment. Proc. South-East Asian Reg. Conf. on Soil Engineering, 6th, Tapei, Taiwan, pp: 293-506.

Gidigasu, M.D. and Gogo, J.O., 1980. Engineering geology and geotechnics of weathered Accra shales. Proc. Reg. Conf. Africa S.M.F.E., 7th, Accra, Vol.2, pp:741-756.

Gidigasu, M.D. and Mate-Korley, E., 1980. Highway geotechnical characterisation of residual micaceous soils over granite. Proc. Reg. Conf. Africa S.M.F.E., 7th, Accra, Vol.2, pp:831-844.

Gidigasu, M.D. and Appeagyei, E. 1984. Shallow foundation conditions in tropical residual soils in relation to the environment. Proc. Reg. Conf. Africa S.M.F.E., 8th, Harare, Zimbabwe, Vol.1, pp:195-201.

Gidigasu, M.D. and Asamoa-Boadu, A., 1984. Ghana's experience in trying to provide low cost houses for the people. Proc. Intern. Conf. on Low Cost Housing for Developing Countries - Roorkee, India, Vol.II, pp:861-870.

Gidigasu, M.D. and Akrofi, S.K., 1984. Research needs and priorities for housing and construction activities in

Ghana. Paper presented at Intern. Seminar on Research Needs and Priorities for Housing and Construction Activities in Developing Countries. University of Lund, Sweden, LCHS/Section V., pp.14.

Gidigasu, M.D. and Asamoa-Boadu, A., 1986. Twenty-five years of research and practice on low cost housing in Ghana. Proc. of 10th Triennial CIB Congress, 21st-26th September, Washington D.C., Vol.5, pp:1847-1855.

Gidigasu, M.D., 1987a. Development strategies for achieving self-sufficiency in housing in Ghana. Proc. Seminar on "Housing for the greatest number". International Year of Shelter for the Homeless", organised by UNESCO and UNCHS (Habitat), Nov. 30-Dec.3, Kinshasa, Zaire, pp:174-208.

Gidigasu, M.D., 1987b. Multi-disciplinary approach to development of shallow foundation engineering practice for problem tropical and residual soils (Special Lecture). Proc. Reg. Conf. Africa S.M.F.E., 9th, Lagos, Vol.2, pp: 675-701.

Gidigasu, M.D., 1987c. Foundation and design practice for light buildings on expansive soils in developing countries: A Review. Proc. Reg. Conf. Africa S.M.F.E., 9th, Lagos, Vol.1, pp:609-628.

Gidigasu, M.D. and Andoh, M.B. 1987. Shallow foundation engineering practice in problem soils in Ghana. Proc. Reg. Conf. Africa S.M.F.E., 9th, Lagos, Vol.2, pp:869-881.

Gidigasu, M.D. and Kuma, D.O.K., 1987. Engineering significance of lateritisation and profile development processes.

Proc. Reg. Conf. Africa S.M.F.E., 9th, Lagos, Vol.1, pp:3-20.

Gidigasu, M.D., 1988. National Commitment: A key factor in evolving and promoting national economic development in Third World countries - A case study of Ghana's proposed rural housing strategy. Proc. Intern. Seminar organised by WAITRO on "Technological Innovations" in Trinidad and Tobago, 26-30th Sept., pp:49-56.

Gidigasu, M.D., 1988. Potential application of engineering pedology in shallow foundation engineering of tropical residual soils. Proc. Intern. Conf. on Geomechanics in Tropical Soils, 2nd, 12-14 December, Singapore, Vol.1, pp:17-24.

Gidigasu, M.D., 1988. General Report: Proc. Intern. Conf. on Geomechanics in tropical soils, 2nd, Singapore, Vol.2, pp:495-513.

Gidigasu, M.D., 1965. Use of stabilised soil as building material. Paper presented at the 5th Annual Symposium of the Ghana Academy of Sciences, on "The Development of Ghana's Natural Resources", Accra, 18pp. (Unpublished).

Gidigasu, M.D., 1968. Foundations on expansive soils (Literature Review). Building and Road Res. Institute (BRRI), Technical Paper No.23, Kumasi, Ghana, pp.26.

Gidigasu, M.D., 1970a. The engineering characteristics of laterite soils (Literature Review), BRRI Project Report S.M.7, Kumasi, Ghana, pp.31.

Gidigasu, 1970b. The effect of pretreatment on the compaction characteristics of laterite soils. BRRI Project Report SM.6, Kumasi, Ghana, pp.12.

Gidigasu, M.D., 1971. Approach to the identification and classification of tropical soils for highway engineering purposes. A paper presented at a Workshop on African problem soils in pavement construction. Sponsored by USAID in Nairobi, Kenya (Unpublished).

Gidigasu, M.D., 1971. The application of pedological information in the engineering classification of Ghana soils. Paper presented at the 7th Annual Conference of the Soil Science Society of Ghana, Nov. 24-27th, Kwadaso, Kumasi, pp:25 (Unpublished).

Gidigasu, M.D., 1975. The formation and general characteristics of laterites and lateritic soils. (Literature Review), BRRI Project Report SM.2 (revised edition), Kumasi, pp:46 + 4 tables, 24 figures.

Gidigasu, M.D. and Mate-Korley, E., 1982. Stabilisation characteristics of selected Ghanaian soils. BRRI Special Report for GHA/World Bank, Kumasi, pp:14, 80 figures, 53 references.

Gidigasu, M.D., 1984. Building and Road Research in the development of Ghana. Proc. of Special Lectures presented at the Symposium organised by the Council for Scientific and Industrial Research (CSIR) on its Silver Jubilee Celebrations 14-16th Feb., Accra, Ghana, pp:125-140.

Gidigasu, M.D., 1987a. Soils and soil-based materials with potential durability for low cost housing in Ghana.

Special Report prepared for the Commonwealth Science Council (CSC), Building & Road Res. Institute, Ghana, pp:19-126.

Gidigasu, M.D., 1987. Expansive soils in foundation engineering in building practice relevant to developing countries. A special report prepared for the International Council for Building Research Studies and Documentation (CIB): Building and Road Res. Institute, Kumasi, Ghana, pp:119

Gidigasu, M.D., 1988. Characterisation of a typical lateritic loamy clay for the production of adobe and local lime stabilised walling blocks. In: (J.K. Ocloo editor): Some local raw materials for low cost housing in Ghana. Special Report prepared for the Commonwealth Science Council (CSC); BRRI, Kumasi, pp:1-48 (restricted report).

Gidigasu, M.D., 1989. Strengthening existing infrastructure for local building materials development. Paper presented at a Workshop, U.S.T., to celebrate the International Year of Shelter for the Homeless (IYSH), Kumasi, Ghana, 22-26th Feb., (under publication).

Gidigasu, M.D., 1989. Improved laterite materials walling technology in Ghana. Inception and First Technical Report prepared for the International Development Research Centre (IDRC) "Laterite Housing" Project, Centre File: 3-p-88-0152 - BRRI, Kumasi, pp:252 + appendices (Restricted report, unpublished).

Gidigasu, M.D., 1991. Improving laterite materials walling technologies in Ghana. Second Technical Report, IDRC

"Laterite Housing" Project, Centre File: 3-p-88-0152 - BRRI, Kumasi, pp:354 (Restricted Report, unpublished).

Goka, A.M., 1988. Case study of the burnt brick industry in Ghana. Council for Sci. & Indust. Res., Accra, Ghana, 61pp.

Grant, K. and Finlayson, A.A., 1978. The assessment and evaluation of geotechnical resources in urban or regional developments. Eng. Geol., Amsterdam, Vol.12, pp:219-293.

Hammond, A.A., 1981. Durability of bauxite-waste pozzolana cement concrete. Amer. Soc. Test. Mat., Special Technical Publ. 691, Philadelphia, pp:346-356.

Hammond, A.A., 1984a. Foundations for earth buildings in the tropics. Building Research and Practice (January/February), Vol.12, pp:30-36.

Hammond, A.A., 1984b. Acceptability of earth as building materials for housing in Ghana. Proc. Colloq. on "Earth construction technologies appropriate to developing countries", 10-12 Dec., 1984, Brussels, pp:170-175.

Hammond, A.A., 1988. Technical recommendations on standards and specifications for production and use of stabilised soil blocks in Ghana. Background paper presented at the Workshop on Ghana Standards and specifications for production and use of soil blocks and lime; sponsored by the Commonwealth Science Council (CSC) and the United Nations Centre for Human Settlements (UNCHS-Habitat), Accra, 18-22 July, 1988, 46pp.

Hammond, A.A., 1972. Lateritic soils in rural housing. Build International, Vol.5(3), pp:163-166.

Hamilton, R., 1955. Minerals in the Gold Coast (Ghana) soils. J.Soil Sci., Vol.6, pp:312-318.

Hamilton, R., 1964. Microscopic studies of laterite formation. In: Jungerius (editor) Soil micromorphology, Elsevier, Amsterdam, pp:269-278.

Heiman, J.L., 1967. Footings for problem soils. Dept. of Works , Commonwealth Building Station, Sydney, Australia; Technical Study, No.44, pp.59.

Holtz, W.G. and Gibbs, H.J., 1954. Engineering properties of expansive clays. Proc. ASCE, Seporate, No.516, Vol.80, pp:1-28.

Holtz, W.G. and Gibbs, H.J., 1967. Research related to soil problems of the arid Western United States. U.S. Bureau of Reclamation, Denver, Colorado, 31pp.

Houben, G., Guillaud, H., Michel Dayre, Pierre-Yves Bard, 1989. Traite de construction en terre encyclopedie de la construction en terre, Vol.1 Craterre, Centre Simone Sigmoret, Villefontaine, France, 355pp.

Highway Research Record, 1973. Soil erosion: causes and mechanisms, prevention and control. Special Report No.135, 141pp.

Hirashima, K.B., 1948. Highway experiences with thixotropic volcanic clay. Proc. Highw. Res. Board, Vol.28, pp:481-494.

Hondros, E.D., 1988. Overview: Materials: A Perspective, ATAS, Vol.5, UNCSTD., United Nations, New York.

Indian Standards Institution, 1961. Specification for soil-cement blocks used in general building construction. Ind. Std. Inst., 1725 - 1960, New Delhi, 10pp.

Ingles, O.G. and Metcalf, J.B., 1974. 37pp. Butterworth & Co. (Publishers) Ltd., London, W.C. 2B 6AB, England.

Ingles, O.G. and Metcalf. J.B., 1972. Soil Stabilisation. Butterworths, Melbourne, 374pp.

International Co-operative Alliance, 1980. Housing Committee. Co-operative Housing. Leutzeallee 107. D-100 Berlin 33. International Co-operative Alliance, 329pp.

International Council for Building Research Studies and Documentation (CIB), 1983. Report and Conclusions, 9th CIB Congress, Stockholm, 342pp.

International Council for Building Research Studies and Documentation (CIB), 1986. Proc. 10th Trianial Congress of CIB on Advancing Building Technology; Sub theme: Shelter for the Homeless in Developing Countries, Washington D.C., Vols. 4 & 5; pp:1123-1966.

International Council for Building Research Studies and Documentation (CIB), 1983. Appropriate building materials for low-cost housing. Proc. Symp. Nairobi, Kenya, 7-14 Nov., 1983, 2 vols, 736pp.

International Council for Building Research Studies and Documentation (CIB) and International Union of Testing and Research Laboratories for Materials and Structures (RILEM), 1983. Appropriate building materials for low cost housing: African region, E & F.N. Spon, London, 2 vols, 821pp.

International Development Research Centre (IDRC), 1990. Strategic choices for sub-saharan Africa: Summary of Responses, 32pp.

International Labour Organisation (ILO) and United Nations Industrial Development Organisation (UNIDO), 1987. Small-scale brick making. International Labour Office, Geneva, Technical Memorandum No.6, 210pp.

Irfan, T.Y., 1988. Fabric variability and index testing of a granitic saprolite. Proc. Intern. Conf. Geomechanics in tropical soils, Singapore, Vol.1, pp:25-35.

Junner, N.R., 1946. Progress in geological and mineral investigations in the Gold Coast (Ghana). Geological Survey Dept., Accra, Ghana, Bull.16.

Kesse, G.O., 1974. Local materials resources for the production of construction materials. A paper presented at a Concerence on "Achievement of Cost Reducation in Public Construction", June, Building & Road Res. Institute, Kumasi, Ghana, 45pp.

Kesse, G.O., 1985. The mineral and rock resources of Ghana. A.A. Balkema, Rotterdam, The Netherlands, 620pp.

Kiran, Mukerji, 1986. Soil block presses. German Appropriate Technology, GATE, Eschborn, 128pp.

Koita, Fodie, 1987. Building with earth. Proc. Inter. Seminar on "Housing for the Greatest Number", International Year of Shelter for the Homeless, Kinshasa, Zaire, November 30th - December 3rd, 1987, pp:141-159.

Kubiena, W.L., 1948. Entwicklungslehre des Bodens, Springer-Verlag, Vienna.

Kellog, C.E., 1949. Preliminary suggestions for the classification and nomenclature of great soil groups in tropical and equatorial regions. Com. Bureau of Soil Sci., Tech. Comm. 46, pp:76-85.

Kellog, C.E., 1941. Climate and soil. Year Book of Agriculture, 1941, U.S. Dept. Agric., pp:262-291.

Kirkendale, G.A., 1975. A laboratory manual for testing clays for use in the production of building products. Building & Road Res. Institute, Kumasi, Ghana, Special Report No.6, 19pp.

Kirkendale, G.A., 1975. Structural clay industry in Ghana. Building & Road Res. Institute, Kumasi, Ghana, 21pp, (restricted report).

Laing, T., 1964. Tropical soils: Characteristics and airphoto interpretation. Cornell Univ., Rept. AFCRL-64-937, 163pp.

Loughnan, F.C., 1969. Chemical wethering of silicate minerals. Elsevier, New York, N.Y., 154pp.

Lohnes, R.A., Demirel, T., Tuncer, E.R., 1976. Strength and structure of laterites and lateritic soils. Eng. Res. Inst., Iowa State University, Ames, Iowa, 85pp.

Lohnes, R.A., Fish, R.O. and Demirel, T., 1971. Geotechnical properties of selected Puerto Rican soils in relation to climate and parent rock. Geol. Soc. Am. Bull.82:2671-2624.

Lunt, M.G., 1980. Stabilised soil blocks for building. Brit. Overseas Building Notes No. 184, Garston, Watford, 15pp.

Lambe, T.W., 1960. The character and identification of expansive soils. Federal Housing Administration, Washington D.C., Technical Report, 45pp.

Lambe, T.W., 1962. Soil stabilisation. In: (Leonards edited), Foundation Engineering. McGraw-Hill Book Company, New York, pp:351-437.

Latorex: Drostholm Products A/S dk-2950 Vedback, Denmark.

Leadabrand, J.A., Norling, L.T. and Hurless, A.C., 1957. Soil series as a basis for determining cement requirements for soil-cement stabilisation. Highway Res. Board, Bull.148, 17p.

Little, A., 1967. Laterite. Proc. Asian Reg. Conf. Soil Mech. Found. Eng., 3rd, Haifa, Vol.2, pp:61-71.

Lacroix, A., 1913. Les laterites de la Guinee et les produits d'alteration qui leur sont associe. Nouvelle Arch. Museum Hist. Nat., 5, pp:255-356.

Maignien, R., 1966. Review of research on laterites. Nat. Resource Res. IV, UNESCO, Paris, 148pp.

Mathur, G.O. (undated). Technology of mud houses - state of the art report; CIB, UNRHC for ESCAP, New Delhi, 10pp.

Mathur, G.O., 1984. Appropriate technology for construction of earthquake resistant mud-houses. Intern. Symposium on Earthquake Relief in Less Industrialised areas. Zurich, pp:129-131.

Mathur, G.O., 1985. Improving earth houses. Building Research and Practice (May/June, 1985), Vol.13, pp:161-165.

McHenry, P.G., 1984. Adobe and rammed earth buildings. John Wiley and Sons, New York, 217pp.

Ministry of Construction and Communications, 1962. Handbook on rural housing, villages and peri-urban development in Ghana. Ministryof Information, Accra, 63pp.

Ministry of Works and Housing (Ghana, 1977. Draft report on the National Housing Committee on the development of local building materials. Ministry of Works and Housing, Accra, 94pp.

Ministry of Works and Housing (Ghana), 1986a. National Housing Policy. Report of National Committee, Accra, 85pp.

Ministry of Works and Housing (Ghana), 1986b. Draft Housing Policy and Action Plan 1987-1990. Min. of Works and Housing, August, 1986, Accra, Ghana, 47pp.

Ministry of Finance and Economic Planning (Ghana), 1987. Public Investment Programme (PIP), 1986-88, Vol.1, Main Report, Ministry of Finance & Economic Planning, Accra, 121pp.

Ministry of Industries, Science & Technology (Ghana), 1985. Summary of conclusions of seminar on New Technologies applicable to Africa Building Materials. Summary of Seminar sponsored by UNIDO, Accra, Ghana (unpublished).

Ministries of Economic Planning, Works and Housing, and Industries (Ghana), 1976. Report of seminar on the formulation of a national plan of action for the manufacture and use of bricks and tiles, 23-24 Feb., Building & Road Res. Institute, Kumasi, Ghana, 22pp.

Ministry of Education (Ghana) (Technical Division), 1988. Personal communications on number of Technical Institutes and Polytechnics in Ghana.

Mitchell, J.K., 1960. Limestone of Ghana. Geological Survey Dept., Accra, Ghana, Bull.23.

Mitchell, J.K., 1976. Fundamentals of soil behaviour. John Wiley and Sons, New York, 422pp.

Mitchell, J.K. and Hooper, D.R., 1961. Influence of time between mixing and compaction on properties of a lime-stabilised expansive clay. Highw. Res. Board Bull.304; 35-50.

Muktabhant, C. and Ongskul, 1960. Stabilisation of lateritic soil with sand. proc. of the Spec. Session on Eng. Prp. of Lateritic Soils, 7th, Int. Conf. S.M.F.E., Mexico, Vol.1, pp:115-119.

Massachussetts Institute of Technology (MIT), 1952. Proc. Conf. on soil stabilisation, June, 1952.

Means, R.E. and Parcher, J.V., 1963. Physical properties of soils. Constable and Company Limited, London, 464pp.

Mohan, Rai and Jaisingh, M.P., 1985. Advances in Building materials and construction. Central Building Research Institute, Roorkee, India, 452pp.

Mills-Tetteh, R., 1985. Rural construction technology at Kainji - A case study. Housing Science, Vol.9, No.2, pp:91-100.

Netterberg, F., 1971. Calcrete in road construction. National Institute for Road Research, Pretoria, Bulletin 10, 73pp.

Netterberg, F., 1975. Self stabilisation of road bases: Facts or fiction. Proc. Reg. Conf. S.M.F.E., 6th, Durban, Vol.1, pp:115-119.

Nwoko, V.O. and Hammond, A.A., 1978. Pozzolana from bauxite-waste. Conservation and recycling. Pergamon press, Vol.2, pp:43-47.

Nye, P.H., 1954. Some soil forming processes in humid tropics. J. Soil Sci., Vol.5, pp:7-21.

Nye, P.H., 1955. Some soil forming processes in humid tropics. J. Soil Sci., 6(1): 51-83.

Nixon, J.K. and Skipp, B.A., 1957. Airfield construction on overseas soils, Part 5, Laterite: Part 6, Tropical red clays. Proc. Inst. Civil Eng., London, Vol.8:253-292.

Nanda, R.L. and Krishnamachari, R., 1958. Study of soft aggregates from different parts of India with a view to their use in road construction. 1. Laterites. Central Road Res. Inst., India, Road Res. Paper 15, 32pp.

Nascimento, V., 1959. Laterites of Portuguese overseas territories. Nat. Civ. Eng. Lab., Mem.141 (unpublished).

Nascimento, V., De Castro, E. and Rodrigues, M., 1964. Swelling and petrification of laterite soil. Nat. Eng. Lab., Lisbon, Tech. Paper 215:19pp.

Oades, J.M., 1963. The nature and distribution of iron compounds in soils. Soils Fertil.26:69-80.

Obeng, H.B., 1970. Characterisation and classification of iron pan soils of Ghana. Ph.D Thesis, Library, Iowa State University, Ames, Iowa (unpublished).

Okine, J.S., 1971. Block Press Handbook for making soil blocks with "TEK-Block" Press. Dept. of Housing & Planning Research, Univ. of Sci. & Tech., Kumasi, Ghana, 29pp.

Ofori, George, 1985. Indigenous construction materials programmes - Lessons from Ghana's experience. Habitat Int., Vol.9, No.1, pp:71-79.

Okot-Uma, W'O. R., 1987. Indicators for performance and environmental impact of mud houses in rural and sub-urban human settlements (Africa). Commonwealth Science Council Publications, Technical Series No.218 (1987), ISP-24, pp: 185-200.

Okot-Uma, W'O, R., 1987. A survey of local building materials and housing construction designs. Commonweath Science Council Publications, Technical Series No.240, 89pp.

Ola, S.A., 1980. Mineralogical properties of some Nigerian residual soils in relation with building problems. Eng. Geology, Amsterdam, Vol.15, pp:1-13.

Opeku, Y.A., 1978. Housing rural communities (Atakpame houses). Rural Housing Research Series RH-1, Building & Road Res. Institute, Kumasi, Ghana, 50pp.

Okyere, J.N., 1978. Brick production in a continuous oil-fired kiln - Fumesua Brick Project. Building & Road Research Institute, Kumasi, Ghana, 39pp.

Opoku-Mensah, D., 1974. Incentives for low industrial manufacture of building materials. Paper presented at Conference on "Achievement of Cost Reduction in Public Construction", Accra, June, 1974, 5pp.

Owusu, D.J., 1971. A review of housing policies and programmes since the Government of Sir Allan Burns. Building & Road Res. Institute, Kumasi, Ghana, 20pp (unpublished).

Olier, D., 1969. Weathering. Oliver and Boyd, Edinburgh, 304pp.

Prescott, J.A. and Pendelton, R.L., 1953. Laterites and lateritic soils. Commonwealth Bur. Soil, Tech. Comm., 47, 51pp.

Peck, R.B., 1971. Engineering implications of tropical weathering and lateritisation. Seminar on laterite and other problem soils of Africa. Univ.Sci. Tech., Kumasi, Ghana, January, 1971. (unpublished lecture).

Plancherel, Jean-Marie, 1983. A morphological classification of lateritic ironstone and ferriginised rocks in Northern Nigeria. Nig. Journal Sci., Vol.1(2), pp:161-173.

Quagish, Samih, 1983. Performance of low-cost housing in Jordan. Sponsored by United Nations. Housing Science, Vol.7, No.3, pp:283-295.

Road Research Laboratory, 1952. Soil mechanics for road engineering, H.M.S.O., London, 541pp.

Reginatto, A.R. and Ferrero, J.C., 1973. Collapse potential of soils and soil-water chemistry. Proc. Intern. Conf. Soil Mech. Found. Eng., 8th, Moscow, Vol.2.2, pp:177-183.

Remillon, A., 1967. Road research in French speaking African countries. Ann. Inst. Bat. Trav. Publ., 231-232: 366-388 (in French).

Roderick, G.L., 1972. Review of particle size classification s of soils. Highw. Res. Board, Record 405, pp:75-86.

Rohatgi, P., 1988. Capacity building for materials science and technology in developing countries. ATAS, UNCSTD, Vol.5, pp:95-97.

Ritonga, S.M., 1984. Research and development on building materials and construction systems in Indonesia. 1st Technical Board Meeting, Regional Network in Asia for Low-cost building materials technologies and construction systems. Baguio City, October 10-20, 1984, Philippines, 22pp.

Rodsawasdi, Direk and Thanmaron, C., 1984. Technical and economic aspects of interlocking soil cement block. Intern. Colloquium on earth construction technologies appropriate to developing countries. December 10-12, Brussels, pp:374-380.

Ruddock, E.C., 1967. Residual soils of the Kumasi district. Geotechnique, 17:359-377.

Rutka, A., 1961. Correlation of engineering and pedological soil classification in Ontario. In: R.E. Legget (editor), Soils of Canada. Royal Society, Canada; Spec. Publ.3, pp:183-192.

Sebestyen, Gy, 1984. Research priorities for building materials industries in developing countries. UNIDO, Vienna, Report ID/WG.425/1, 54pp.

Shadmon, A., 1975. Natural Building stone development project for Ghana. UNIDO Project No.15/GHA/74/006/11-02/03, Restricted Report, UNIDO, Vienna, 20pp.

Schreckenbach, H. and Abankwa, J.G.K., 1983. Construction Technology for a tropical developing country. GTZ and Univ. of Science & Technology, Kumasi, Ghana, 338pp.

Sherman, G.D., 1952. The genesis and morphology of the alumina-rich lateritic clays. In: Clay and laterite genesis. Am. Inst. Min. Metall. Eng., New York, pp:154-161.

Shergold, F.A., 1945. Physical tests on three samples of laterite rock. Brit. Road Res. Lab., Note 578 (unpublished).

Shergold, F.A., 1948. A review of available information on the significance of roadstone tests. Brit. Road Res. Lab (UK), Tech. Paper 10, 14pp.

Sidibe, Balla, 1985: Understanding adobe. Volunteers in Technical Assistance (VITA), Arlington, Virginia, USA, 26pp.

Sherard, J.L., Dunnigan and Decker, R.S., 1976. Identification and nature of dispersive soil. J. Geotech. Div. Am. Soc. Civil Engrs., Vol.102, No.GT4, pp:287-301.

Sherwood, P.T., 1958. A study of the pedological classification of soils in relation to soil-cement stabilisation. Road Res. Lab. (U.K.), Note 3284, Berkshire (unpublished).

Sherwood, P.T., 1967. Classification test on African red clays and Keupar Marl. Q.J. Eng. Geol., London, Vol.1, No.1, pp:47-55.

Sherwood, P.T., 1968. The properties of cement stabilised materials. Brit. Road Res. Laboratory, Crowthorne, Report LR.205, 31pp.

Sherwood, P.T., 1970. The reproducibility of the results of soil classification and occupation tests. Brit. Road Res. Lab., Report LR.339 (unpublished).

Smith, R.G., 1974. Building with soil-cement blocks. Building Res. and Practice, Paris, March/April, pp:98-102.

Sowers, G.F., 1962. Shallow foundations. In: Leonards (editor); Foundation Engineering, McGraw-Hill Book Company, New York, pp:525-632.

Sperling, R., 1961. Soil-cement blocks: A field test for suitable mix proportions. West African Building Research Institute (WABRI), Accra, Ghana, Note 2, 4pp.

Sperling, R., 1962. Soil-cement blocks: Effect of soil composition on durability and other properties. West African Building Research Institute (WABRI), Accra, Ghana, Note 14, 14pp.

Simonson, R.G., 1974. Non-agricultural applications of soil surveys. Development in soil science, Vol.4, Elsevier, Amsterdam, 178pp.

Spence, R.J.S. and Cook, 1983. Building materials in developing countries. John Wiley & Sons Ltd., New York, 338pp.

Stulz, R., 1981. Appropriate building materials. SKAT Publications, St. Gallen, Switzerland, 324pp.

Salberg, J.R. and Smith, P.C., 1965. Pavement design over expansive clays: Current practices and research in the U.S.A., Proc. Inter. Res. and Eng. Conf. on Expansive Soils, A & M Pess, Texas, p.242.

Solas, J.A.J., Justo, J.L., Romana, M. and Faraco, C., 1973. The collapse of gypseous silts and clays of low plasticity in arid and semi-arid climates. Proc. Intern. Conf. Soil Mech. Found. Eng., 8th, Moscow, Vol.2.2, pp:193-199.

Shellman, W., 1979. Considerations on the definition and classification of laterites. Proc. Intern. Seminar on Lateritisation Processes, Trivandum, India, pp:1-10.

SKAT, 1988. Appropriate Building Materials (compiled by Roland Stulz and Kiran Mukerji), Swiss Centre for Appropriate Technology, St. Gall, 430pp.

Skempton, A.W., 1953. The "Colloidal Activity" of clays. Proc. Intern. Conf. Soil Mech. Found. Eng., 3rd, Zurich, Vol.1, pp:57-62.

Sueoka, T., 1988. Identification and classification of granitic residual soils using chemical weathering index. Proc. Intern. Conf. Geomechanics in tropical soils, Singapore, Vol.1, pp:55-61.

Stephen, I., 1953. A petrographic study of a tropical black earth and grey earth from the Gold Coast. Journ. Soil Sci., Vol.4, 211-219.

Thornthwaite, C.W., 1948. An approach to a rational classification of climate. Geol. Review, Vol.38, pp:55-94.

Tuncer, E.R., 1988. Pore size distribution characteristics of tropical soils in relation to engineering properties. Proc. Intern. Conf. Geomechanics in Tropical soils, Singapore, Vol.1, pp:63-70.

Tuncer, R.E. and Lohnes, R.A., 1977. An engineering classification of certain basalt-derived lateritic soils. Engineering Geology, Amsterdam, Vol.II, No.4, pp:319-339.

Tyler, R.G., 1961. Sandcrete blocks. West African Building Research Institute (WABRI), Note No.4, 6pp.

Tateishi, H., 1967. Basic engineering characteristics of high moisture tropical soils. Proc. Conf. W. Assoc. State Highway Official, Honolulu, July 12, 1967, 19pp.

Trindade, S.C., 1988. Executive Summary to ATAS, Vol.5, UNCSTD, United Nations, New York.

Tubey, L.W., 1961. A laboratory investigation to determine the effect of mica on the properties of soils and stabilised soils. Brit. Road Res. Lab., Note 4077 (unpublished).

Thompson, B.W., 1965. The climate of Africa. Oxford University Press, London 132pp.

Thorp, J. and Smith, B.D., 1949. Higher categories of soil classification; Order, sub-order and great soil groups. Soil Sci., 67; 119-126.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1985. The use of selected indigenous building materials with potential for wide application in developing countries. UNCHS (Habitat), Nairobi, Kenya, 70pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1984. Small-scale building materials production in the context of the informal economy, UNCHS (Habitat), Nairobi, Kenya, 40pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1986. Earth construction technology (4 manuals on basic principles of earth application, production of rammed earth, adobe and compressed soil blocks, design and construction techniques, surface protection), UNCHS (Habitat), Nairobi, Kenya, 210pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1986a. Manual on basic principles of earth application, UNCHS (Habitat), Nairobi, Kenya, 50pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1986b. Construction technology. Manual on production of rammed earth, adobe and compressed soil blocks. UNCHS (Habitat), Nairobi, Kenya, 37pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1986c. Earth construction technology. Manual on design and construction technique. UNCHS (Habitat), Nairobi, Kenya, 66pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1986d. Earth construction technology. Manual on surface protection. UNCHS (Habitat), Nairobi, Keyna, 57pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1987. Earth construction technology - Part 2. Low cost technology for production of adobe, rammed earth and compressed blocks. Technical Note No.13, Nairobi, 4pp.

United Nations Centre for Human Settlements (UNCHS - Habitat), 1984. Government policy guidelines to improve the efficiency of the construction industry. UNCHS (Habitat), Nairobi, Kenya, 45pp.

United Nations Industrial Development Organisation (UNIDO), 1969. Building materials industry. Monograph N.8, UNIDO, Vienna, 77pp.

United Nations Industrial Development Organisation (UNIDO), 1980. Appropriate industrial technology for construction and building materials. Monographs on appropriate industrial technology, No.12, Vienna, 218pp.

United Ntions Economic and Social Council (ESC for Western Asia), 1987. Soil construction as an energy-efficiency material for low cost housing. UNCHS (Habitat), Nairobi, Kenya, 33pp.

United Nations Centre for Science and Technology for Development (UNCSTD), 1988. Advanced Techology Alert System (ATAS), Materials Technology and Development, United Nations, New York, Vol.5, 156pp.

United Nations Development Programme (UNDP), 1992. Choices: The human development magazine, United Nations, New York, 38pp.

United Nations Economic and Social Commission for Asia and the Pacific, RILEM and CIB, 1987. Building materials for low-income housing. Summary Report of Symposium, 20-26 June, 1987, Bangkok, 47pp (and annexes).

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), RILEM and CIB, 1987. Summary Report on Building Materials. Report, Symposium, Bangkok, 20-26 January, 1987, 13pp.

UNESCO/ECA, 1964. Organisation of research and training in Africa in relation to the study, conversation and utilisation of natural resources. Final Report on the Lagos Conference, 28 July to 6 August, 1964, UNESCO, Paris; 102pp.

Venkataraman, T.S. and Venkatasubramanian, V., 1977. Temperature studies on bituminous pavements in the tropics. J. Australian Road Res. Board, Vol.7, No.1, pp:32-37.

Vargas, M., 1988. Characterisation and classification of tropical soils. Proc. 2nd Inter. Conf. Geomechanics in tropical soils, Singapore, Vol., pp:71-75.

Vallerga, B.A., Schuster, J.A., Love, A.L. and Van Til, C.J., 1969. Engineering study of laterite and lateritic soils in connection with construction of roads, highways and airfields. U.S. AID, Rept. AID/CSD-1810, 165pp and appendices.

Vine, H., 1949. Nigerian soils in relation to parent material. Commonwealth Soil Science, Tech. Comm., 46:22-29.

Webb, T.L., Colliers, T.F. and Stutterheim, N., 1950. The properties of compacted soil-cement mixtures for use in building. Natl. Bldg. Res. Inst., Pretoria, South Africa, 62pp.

West African Building Research Institute (WABRI), 1957. Draft specifications for soil-cement blocks. West African Building Research Institute, 3pp (unpublished).

Wolfskill, Lye, A. (undated). Handbook for building homes in earth. Dept. of Housing and Urban Development, Div. of Intern. Affairs, Washington D.C., 159pp.

Wills, J.B., 1962. Agriculture and landuse in Ghana. Oxford University press, London, 304pp.

Wright, E.A., 1974. The training programme for professional civil engineers. Paper presented at the Conference on

"Achievement of Cost Reduction in Public Construction", June, 1974. Building & Road Res. Inst., Kumasi, 8pp.

Wright, A., 1977. Rural latrines: Report of a Technical Advisory Group Meeting, Kumasi, sponsored by the IDRC, 12-15 July, 1977, 81pp + figures.

Wagner, A.A., 1957. The use of the unified soil classification system by the Bureau of Reclamation. Proc. Int. Conf. Soil Mech. Found. Eng., 5th, Paris, 1:125-134.

Wallace, K.B., 1973. Structural behaviour of residual soils of continually wet highlands of Papua, New Guinea. Geotechnique, London, Vol.23(2), pp:203-218.

Williams, R.J.J., 1988. The need for inter-disciplinary research and development structures, ATAS, UNCSTD, New York, Vol.5, pp:103-105.

White, B.G., 1962. A review of the problem of low-cost housing in West Africa. West African Building Res. Institute, Accra, Ghana, 58pp.

Tomlinson, M.J., 1986. Foundation design and construction, John Wiley & Sons, New York, 749pp.

Townsend, F.C., Manke, G.P. and Parcher, J.V., 1969. The effect of remoulding on the properties of a laterite soil. Highw. Res. Board, Record 284, pp:76-84.

Townsend, F.C., Manke, G.P. and Parcher, J.V., 1971. The influence of sesquioxides on laterite soil properties. Highw. Res. Board, Record 374, pp:80-92.

Wooltorton, F.L.D., 1955. Engineering pedology and soil stabilisation. Highw. Res. Board Bull.108, pp:29-57.

Yoder, E.Y., 1957. Principles of soil stabilisation. Proc. Ann. Road School, 43rd, 92, 41(3):95-106.

Yogi, A., 1980. Prevalent local building materials and suggestions for their improved use in rural areas. National Building Organisation. Journal, Vol.XXV, New Delhi, pp:17-21.