"STUDIES ON SOME INDIAN BUILDING STONES AND THEIR ENGINEERING APPLICATIONS."

By

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This is to certify that the thesis entitled "Studies on Some Indian Building Stones and their Engineering Applications" that is being submitted by Sri Praphulla Kumar, M.Sc., for the award of the Ph.D. degree of the University of Roorkee is a result of bonafide research work carried out by him under our supervision and guidance. The results embodied in this thesis have not been submitted for the award of any degree or diploma of this University. The candidate has completed the specified period (equivalent to 24 months of full time research).

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PREFACE

How does mineral quartz or felspar concerns an engineer? Is this rock suitable as a building material? On many occassions such queries are raised by the engineers, architects and the contractors. Hence, it was considered useful to carry out some experiments on the building stones of the country, so that it could serve as an aid to those who wish to have a better understanding of the rocks used as building materials.

In this treatment an attempt has been made to combine the knowledge of geology with an engineering outlook, in such a way as to link up the results obtained in the laboratory with the practical problems of the building stone industry. The aim has not been merely a descriptive and fundamental research, but the applied aspect has always been kept in view. For this reason critical surveys of present methods of quarrying, testing and evaluating the stones, together with the suggestions as to future lines of approach, have been given where ever possible.

About six years back when the writer was engaged on the research programme of the Central Building Research Institute, Lt. Gen. Harold Williams, Director, suggested that it would be worth-while to choose a topic where some engineering aspects of geology, particularly applied to the building research in India, were involved. Naturally, 'Building Stones' were the first to come to the mind of a student of geology. In order to learn more of the problem so that a significant contribution could be possible, a probe was made into the pages of the available literature. Later, the study was supported by field surveys of the stone constructions and the quarrying activities in the country. Soon, it was realized that though there are many scattered reports and passing notes on the subject, there is no comprehensive account available on the 'Indian Building Stones', their use and the methods of testing. On the other hand, information was available on the building stones of many a countries, but the literature was too meagre about the Indian resources. Further, the importance of such a study was appreciated all the more as the use of 'Indian Stone' had recently received a revival as facing material in India and as an ornamental stone in the markets of foreign countries.

It will be realized that the bou[illegible] the topic under study are very vast, and within the limits of these pages it is very difficult to treat, even briefly, all the ramifications of the subject. Hence, by making a somewhat arbitrary choice, it has been endeavoured to include all that was considered most useful and could be performed within the available time and the facilities.

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CONTENTS

ILLUSTRATIONS

A. LIST OF PLATES

B. LIST OF FIGURES

THE ENGINEERING APPLICATION OF BUILDING STONES AND AGGREGATES IN INDIA

ABSTRACT

Stone is one of the two staple requirements of the building industry in India. Besides its use as a dimension stone, it forms a major constituent of concrete. In many areas of India suitable clays for the manufacture of bricks are scarce and the stones being available in plenty have been fulfilling the need of building constructions. However, the survey has shown that stone is slowly being priced out of the market because of its high cost and lack of information regarding its availability, uses and testing techniques.

It has been observed that the reduction in cost is only possible through proper mechanization of stone quarries. This is an intricate problem peculiar to Indian conditions, as it involves economic factors, labour conditions and availability of the required type of machinery. A brief review of the use of building stones with the present methods of quarrying has been given. New methods of quarrying and sawing, as can find potential utility under Indian conditions, have been proposed. The rate of productivity of these new methods is also discussed. A design of a new 'Flag Saw' having special utility under Indian conditions has been given.

Based on information collected during actual field survey, an attempt has been made for the first time to catalogue the existing building stone quarries of the country along with the type of rock quarried at all these places.

The scanty data available on the physical, chemical and engineering characteristics of Indian stones and aggregates, appear to be the chief reason for the lack of confidence of efficient use of stone amongst the engineers, contractors, builders and other users in the country. With a view to bringing together all these properties for use in the industry, properties such as true and apparant specific gravity, water absorption, saturation co-efficient, porosities, pore structures etc. have been determined and the applicability discussed after the mutual relationship of these properties was determined. Similarly, Engineering properties like compressive strength, modulus of Rupture and shearing strength have also been determined both for parallel and perpendicular directions, in the rift planes. On the basis of the results a new scheme of classification of Building Stones according to their toughness has been suggested.

CHAPTER I.

G E N E R A L

INTRODUCTION

'Stone' and 'Brick' are the staple requirements of the building industry in any country. Concrete now the most commonly used structural material contains mainly stone in its composition. It is, thus, only a modified way of using stone and has the advantage of plasticity, which can be exploited in order to meet the modern demand for 'in situ' constructions. The usefulness of stone as a structural material can be treated under three heads - a) beauty and ornamentation, b) structures requiring a very high quality material, and c) residences.

Stone has always been regarded a material 'par excellence' in its ornamental and aesthetic effects. Thin slabs of stone sheathe most modern floors and facings of important buildings and steel sky scrapers (Pl.1 Fig. 1&2). Stone is still preferred by - architects and property owners because in addition to imparting beauty to the structures it combines high strength and durability.

The concretes are prone to failure caused by both physical and chemical reactions. In addition to thwarting these effects, the dream of the engineer to produce concrete as hard as rock is yet to be realized.

However, for the ordinary dwellings and other modest constructions, stone has a serious competitor in bricks and other newly introduced cement products. But even in brick and

Dynamic modulus of elasticity has been calculated by using transverse pulse velocities by sonic and ultra-sonic methods. Results have been discussed in the light of the above mentioned properties. Based on the information so obtained a method of finding out the 'Grain Direction' in case of slates has been suggested.

Details of the experimental procedures are given along with the equations used in calculation.

Stones have also been examined petrographically from the point of view of building properties.

It is realized that the applied engineering properties and the elements of strength and durability in stone are intimately connected with most of the physical, chemical and petrographic properties. Curves relating to the salt crystallization tests for durability have been given. Flaws which escape detection in the standard procedures are pointed out.

An attempt is made to evaluate the mineralogic and petrographic properties of stone in relation to its physical and engineering properties. Factors which are responsible for the strength development in building stones are discussed from petrography point of view. This aspect appeared to be partly neglected or entirely ignored so far.

The decline in the art of stone masonry and the lack of knowledge about stones, has resulted in some common defects in constructions. These defects have been noted for consideration while laying down the specifications for stone masonry works under Indian conditions.

Slate is an important roofing material in tropical regions of India, but the builders do not seem to possess the technique of laying slates. Hence, specifications for laying slate roofs have been suggested. Similarly specifications for stone trusses have also been proposed.

Concrete made from Indian rocks and minerals has been studied and the influence of the petrographic and mineralogic properties of these aggregates was noted. Role of minerals, rock textures and structures are discussed from the point of view of petrography and concrete technology.

Rock aggregates play a very significant role in the phenomenon of strengths development in concrete and a few aspects of the same have been discussed in the light of a few experiments, conducted to evaluate the same quantitatively.

PLATE No.1 Fig.1

STONE AS FACING IN AN IMPORTANT BUILDING (LOK SABHA)

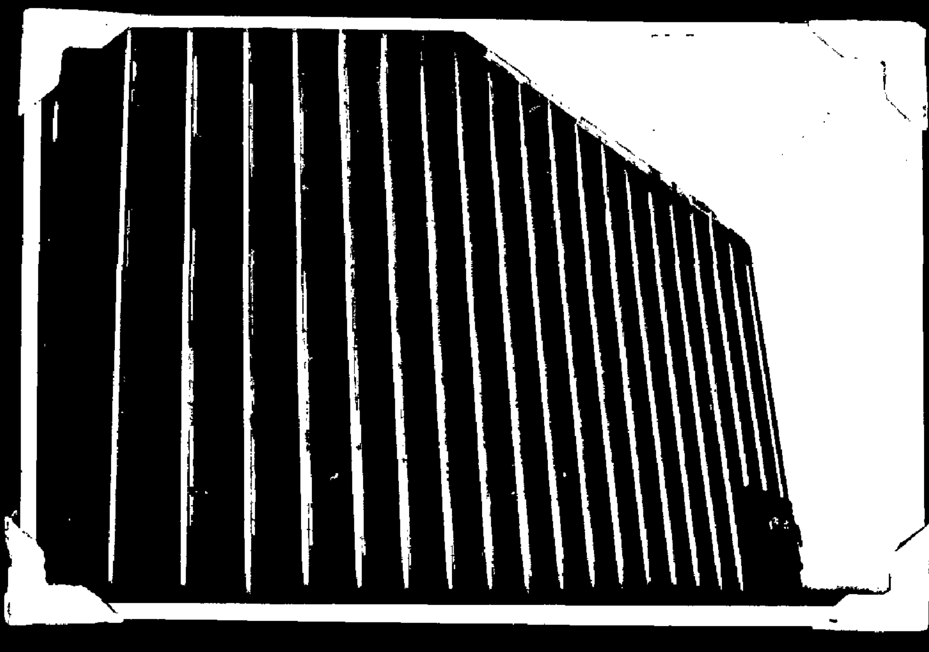


PLATE No.1 Fig.2

STONES SHEATHE STEEL SKY SCRAPERS (NEW DELHI) concrete buildings sills, facings, floors, steps, fire places, warm scotings and base-boards are generally of stone.

In India suitable clays for making bricks are not available in many areas, especially in the vast desert tract of Rajasthan which is fast developing into a densly populated industrial state. In the 20,000 sq. miles area in Deccan covered with black cotton soil, manufacture of suitable bricks is not possible. On the other hand, stone is plentiful in all these areas and is, therefore, extensively used for monuments as well as for the construction of dwellings, be they blocks of flats in big towns or residences in suburbs and villages. In these areas, there has been over past few years a very real fear that the masonry built in native stone may be stopped because of the high cost of the stone itself. Bricks have been supplanting stone and in almost every town the transition from stone to brick can be seen from the centre of the city to the outskirts.

With the ever increasing consumption of coal for steel and other allied industries the supply of coal for the manufacture of bricks has been scarce and is already posing a threat to the brick industry. The cost of inferior class of bricks even has gone up enormously. This is bound to revive the use of stone for building constructions in many areas.

Moreover, at present, there is a tendency amongst architects to design urban houses with random rubble polygonal stone walls as a standard fronts (Pl.2).

PLATE No.2.

(R) RANDOM RUBBLE POLYGONAL STONE WALLS (CBRI, ROORKEE)

A new era in the export of 'Indian Building and Ornamental stones' has opened. Granite and various other kinds of stones are cut and polished and exported to foreign countries for monumental and memorial purposes. These trends indicate a definite revival of the building stone industry in India (Fig.1).

Stone when cut and dressed as dimension stone or broken into aggregate as crushed stone plays a very vital role in the building activity. Obviously an investigation of its properties is essential to help a better understanding of and proper utilization of this material. The lack of data on the physical, chemical and engineering properties of Indian building stones and its knowledge amongst the builders, engineers and contractors have forced them to proceed with little knowledge on the efficient use of stone.

It is now realized that the engineering properties of stones are based on many physical, chemical, petrographical and other properties so that there is need of a general review and approach to collect fresh data. The present lack of information about Indian building stones and natural aggregates results too often in the haphazard selection and use of stone either as a masonry material or as an aggregate.

Strangely enough, this subject has received little attention from the engineering geologists of this country. Except from a few fragmentary reports in the last century published from time to time in the records and memoirs of the Geological Survey of India, there is no comprehensive account on this subject.

It is difficult to trace back the history of previous workers on Indian building stones with any precision mainly because the subject has attracted little attention even from ancient times. However, in the 19th century Hardie (1832)[1] described the stones of Rajasthan for the first time. Later Middleton (1869)[2], Ried (1869)[3], Robinson (1869)[4] and Cowasjii (1871)[5], published reports of their work on the subject of building stones of certain areas.

In 1874[6] and 1890[7] there appeared an account of the distribution of the building and ornamental stones of India in the records of the Geological Survey of India.

In 1875[8] Sills published a note on the subject and reported on certain engineering aspects of the use of building stones.

Thereafter, during the present century, abstracts about the occurrences and uses of building stones have regularly appeared in the annual reports of the Geological Survey of India. Descriptions of the building stones of various states have been given by various authors [6-16] under the treatise on mineral resources of those states.

In 1905 tests were carried out[17] to investigate the characteristics of the Indian Granites in connection with the construction of the Bombay Harbour.

Sineit & Sampat Iyengar (1916)[18] and Hallowes (1922)[19] described the stones of Mysore and Salsette Island respectively.

In 1931[20] there appeared the first account on the weathering characteristics of Vindhyan Building Stones. In the same year Sen A.M.[21] also published an account of the stones of Mysore State.

In 1932-33 Cotter[22] determined the specific gravity and porosity of a few Indian Building Stones available in the Indian Museum at Calcutta. These stones did not include those exploited to-day.

Chandok (1933)[23] and Malhotra (1942)[24] gave an account of quarrying activity at Dharamshala (Punjab) and Makrana (Rajasthan) respectively.

In his book 'Geology of India' Wadia[25] devoted a few pages on the subject of building stones in the Chapter on 'Economic Minerals of India'.

In 1948 Council of Scientific & Industrial Research[26] published a note on the availability of building stones in India.

Recently Brown and Dey[27] in their very informative book 'Indian Mineral Wealth' have devoted one full chapter on the subject of building stones, their availability and uses.

It has been realized that the high cost of stone masonry is mainly due to the price of the stone itself, as available on site. Cost of stone depends mainly on the method of quarrying besides freight. Mostly the quarrying in India is done manually. With the increase in labour charges besides the restrictions imposed by labour unions, the use of modern mechanical methods of quarrying and sawing has become inevitable and the Indian quarry masters are faced with this acute problem. Apparantly this is a difficult but important problem which requires immediate attention if stone has to continue as a structural material. What is more important, is to study the most suitable type of mechanization which can possibly be exploited under the prevailing economic conditions. The mechanization adopted in other countries for increasing the productivity and reducing the cost is in many ways not suitable for India. Certain tools which are not manufactured in the country, at present, prove more expensive to a quarry master than the manual labour. Imported diamond saws are extremly costly to be used with the existing labour conditions. Indian garnet and other corundum bearing minerals found in abundance can be utilized as cheap abrasives for preparing cutting and sawing equipment by using phenol formaldehyde or other synthetic resins as binders. With this in view a "FLAG SAW" for cutting slabs of limestone and slates specially suitable for Indian conditions has been designed, described and illustrated. The quarry owner cannot be expected to try all these methods and hence it would be perhaps best if it is taken over by research organizations. However, after studying the current practices of quarrying and sawing of building stone in other countries, a few methods which can find potential use under Indian conditions have been proposed in Chapter II.

Chapter III deals with the information regarding the existing quarries, their location and the type of products they produce. Such an information has been in great demand and therefore, has been provided by conducting actual field survey and partly through questionnaires issued to various state government departments and quarry owners. Mention of any such deposit which is not being worked at present is purposely avoided so that the whole treatise does not become a mere directory.

Moreover, for this information, there are extensive references in the records and memoirs of the Geological Survey of India and they serve to indicate the potential deposits for future exploitations. In this work mention has been made only of the better known deposits which are being worked at present. Deposits which are not exploited or already abandoned have not been included. In preparing this list, an attempt has been made to follow the new boundaries of the Indian states for denoting the location of the quarries.

Chapter IV deals with the experimental techniques involved in the present investigations for evaluating the stone properties. Petrographic examination reveals the varying nature of the mineralogic composition, texture and structure amongst rocks. This immediately raises the thought that these natural materials present a very complicated variety and each type of rock has its own peculiarities which should be tested, detected and pointed out. It is not feasible to evolve testing procedures for each and every type of rock seperately. Therefore, even an apparantly exhaustive work would perhaps leave lacunae on any investigation pertaining to stones. Hence, only a few important techniques usually followed have been adopted.

In Chapter V the physical properties and chemical composition of a few representative stones have been determined and discussed. Such a data on Indian building stones has not been recorded and it is in great demand at present for use in architecture and engineering. Besides its utility as a reference of these properties, the data has also been discussed from the point of view of explaining stone behaviour in structures under Indian climates. Studies have been conducted on the mutual relationship of these physical properties.

Similarly engineering properties have been determined, recorded and discussed in Chapter VI . No two pieces of stones are alike and every piece prepared for test behaved differently. Obviously, anamolies were constantly observed in the behaviour of stone cubes under stress though these were supposed to be homogeneous and uniform in structure. Stone cubes cut from the same block of seemingly compact material and carefully tested under the same conditions showed remarkably strange variations during the crushing trials. Some cubes developed sudden cracks even at low pressures and got fissured and split into irregular films, flakes or lumps. In many cases the tension was well distributed throughout the whole mass of the cube and very high values were reached before cracks appeared. Causes of these variations have been described.

Based on the physical and engineering properties of stones a "Numerical Scheme of Classification of Building Stones" has been proposed. According to this classification stones are devided into 15 classes and each class signifies its own characteristic range in physical and engineering properties. The classification can be utilized for deciding the cutting rates of rocks depending upon each class of stone. Further, the studies have been conducted on the mutual relationship amongst engineering properties like compressive strength, shearing strength and modulus of rupture.

Chapter VII 'Dynamic Modulus of Elasticity' has been determined by 'Sonic and Ultrasonic' methods. Results have been discussed and concordance between the results obtained seperately by 'Sonic' and 'Ultrasonic' has been pointed out. Studies have been conducted on the relationship between density, compressive strength and the modulus of elasticity. Cause of variations depending upon the rock textures have been pointed out.

Observations of 'Ultrasonic pulse velocities in different directions of a slate have shown variation in two directions, depending upon the 'Grain' or 'Cross Fracture'. A method of detecting the 'Grain' or Cross Fracture' in case of slates has been proposed.

Chapter VIII deals with the general petrographic examination of the building stones that has been carried out to evaluate the elementary conditions on which the strength and actual value of building stone depends. Until these characteristics have been thoroughly worked out and understood in the light of the ultimate use of a stone in structure, there can be little harmony or satisfaction in the usual methods proposed for the investigations and trial of stones. It may be mentioned here that it serves no useful purpose in engineering to describe the pleochroic scheme of minerals or 2V or such other properties which do not bear any relation to the building properties of stones. These have not been included. Quantitative estimation of the mineralogical composition of sandstones have been carried out.

Chapter IX pertains to the petrographic evaluation of the building stones under Indian conditions. Durability studies in the light of petrographic features has shown that in evaluating the characteristics of stone in its adaptation as a building material, attention should be drawn to petrographic and mineralogic features, importance of which has been almost entirely neglected hiterto in this country. A knowledge of these features is essential for framing the standard methods of tests required for correct assessment of different varieties of stone in our trying climate. It has been observed that the accelerated weathering test[27] though useful has limitations. Certain falaws in the stone escape detection by these standard procedures and the same have been pointed out. The elements responsible for the durability and strength in case of building stones have been discussed from the petrography point of view. A quantitative petrographic method of evaluation of durability has been suggested. Factors which seem responsible for the development of strength during seasoning of building stones have been pointed out.

The art of stone masonry is fast disappearing and the beauty, strength and durability is always lacking in stone-buildings. Although this art depends more on practice and individual attainments certain basic principles should be followed in order to reduce the flaws to a minimum. It would be desirable, if some standard practices of laying stone masonry are followed. Some of the defects which require attention in framing the standards have been mentioned in Chapter X.

Building stone has been used in India for a variety of structural purposes in bridges, dams, river training works, as beams to support ceilings, roofing and flooring etc. In many parts of the country, long beams are quarried in various sizes for uses in trusses. Specifications of the suitable stone trusses have been suggested in Chapter X. Further, slate tiles are best suited for pent roofs in a tropical climate. Moreover, in and around the slate occurring areas they are cheaper than A.C. sheets and have an advantage in being smaller members in their periodical replacement in an easier way. Noise and other havocs caused by the slate roofs during rain and hail storms are far less than those by A.C. sheets. Notwithstanding this we find that A.C. sheets are gradually replacing slates for roofing purposes. One reason for its replacement is that the correct method of laying slates is not well known to the builders. Specififications of method of laying slates suitable under Indian conditions has been suggested. A geologist's description of a rock or mineral as granite or felspar is hardly rekoned as an important piece of information by an engineer unless stress is laid on the influence of these materials, as an aggregate, in concrete. Perhaps this missing link is much more important to study than the detailed mineralogic properties of felspar or any other mineral from engineering point of view.

Chapter XI pertains to the influence of mineralogic and petrographic properties of rocks as these influence the strength of concrete. Studies on concrete prepared from rock forming minerals, like quartz and felspar, have been discussed, so that their actual role in a rock when used as an aggregate is clear. Effect of internal texture and structure of rock aggregates on concrete has been point out. A distinction between the 'Soft' and 'Weak' particles have been drawn.

Chemical reactions of aggregates in concrete have been classified and discussed. Investigations on a few unknown chemical reaction have been reported and discussed. Average co-efficient of thermal expansion of rocks on the basis of silica percentage has been calculated and the fire resistance properties of aggregates has been discussed briefly.

In last chapter, a quantitative estimation of the influence of engineering properties, dynamic modulus of elasticity, shape of aggregates, absorption percent and surface texture on the strength of concrete has been done. Results on compression strength, tensile strength of concrete ~~and some~~ have been discussed in the light of petrographic and mineralogic properties.

PART I.

BUILDING STONES

CHAPTER II.

BRIEF HISTORY OF THE USE OF BUILDING STONES AND THE DEVELOPMENT OF QUARRYING ACTIVITY IN INDIA

The architecture of India instantly reveals the use of stone as building material since historic times. During the Buddhist era the art of building in stone had already attained distinction in Indian architecture.

Sandstones of Vindhyan System, suitable for all types of building and engineering works, have been used extensively from Mauryan times. Pillars and great monoliths weighing upto 50 tons polished and inscribed with Emperor Ashoka's edicts were erected at localities often hundreds of miles from their source. The 'Stupa' at Sanchi in M.P. (Pl.3) built of red sandstone blocks, is a segment of a sphere which has a diameter of 110 ft. at the base of the dome, and a height of about 7½ ft. Its massive stone railing of monolithic pillars, 11 ft. high and its four highly ornate gateways each 34 ft. in height bear eloquent testimony to the highly skilled art of production, finishing, sculpture, transport and erection of monuments in Mauryan age.

Vicent Smith writes[27]:-

> "The skill of the stone-cutter may be said to have attained perfection. Gigantic shafts of hard sandstone, thirty or forty feet in length were dressed and proportioned with the utmost nicety, receiving a polish which no modern mason knows how to impart to his material"

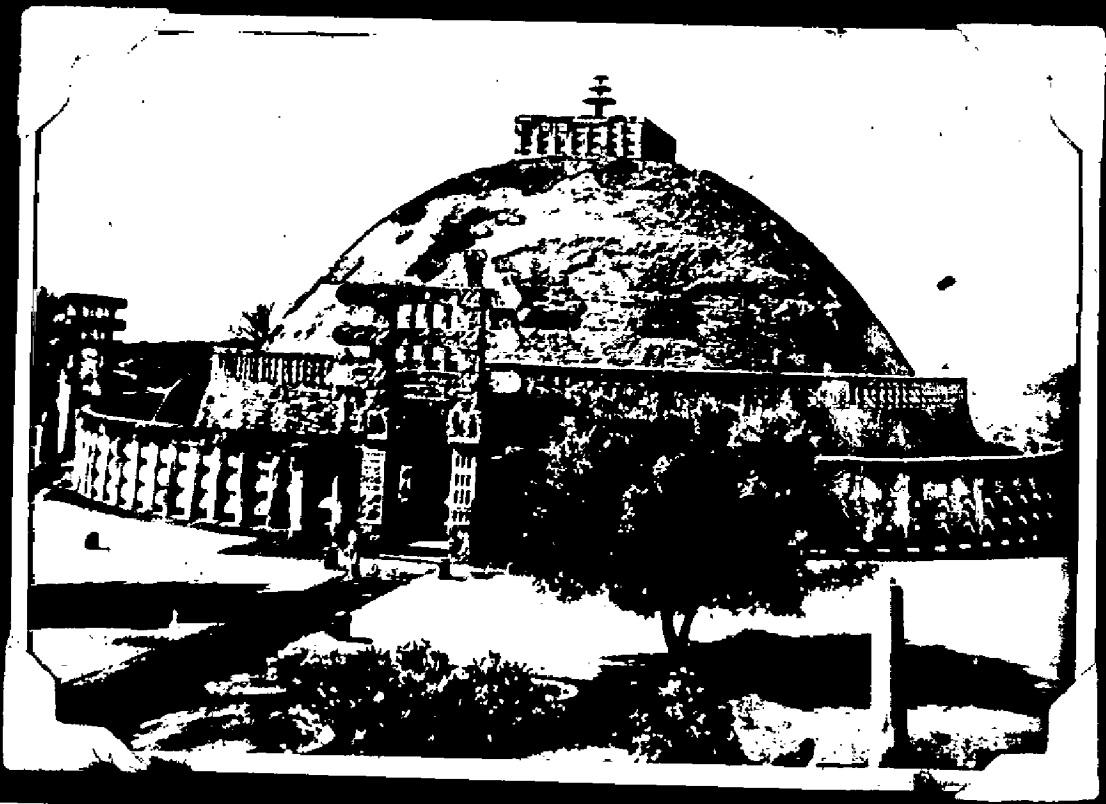


PLATE No.3

STUPA AT SANCHI, BUILT OF SANDSTONE (M.P)

In South India crystalline rocks such as granites, gneisses and charnockites have been used from the time of the pre-historic megaliths onwards. At a later date Dravadian Art began with the Chalukyan period (410-650 A.D). The rock cut outs at Mahaballipuram, Convecevaram, Tanjore, Srirangam, Madura, Rameshwaram and the structures in the ruined city of Hampi (Vijayanagar) near Hopet in Bellary district are all records of this early use of stone as a construction material.

There are fine examples of the use of stone in Jain and Indo-Aryan Styled which flourished from 8th to 13th Century in Orissa, Bengal, Rajasthan and Gujerat.

Examples of architectural capacities of the stone may be seen in old palaces, forts, memorials, temples, mosques and other structures of historical importance in Rajasthan, Delhi and Fatehpur Sikri (Pl.4 Fig. 1&2). The Taj of Agra', which is still an unsurpassed piece of the art of architecture, is made of white crystalline marble from Makrana.

To come to more recent times the largest engineering work of the British Administration in India utilized stone as a construction material (Pl.5 Fig. 1&2). The best buildings in New Delhi, Bombay, Madras, Mysore and various other places are all made of a variety of stones. To-day utility follows beauty.

DEVELOPMENT OF THE QUARRYING ACTIVITY

Past Survey - Little is known about the stone quarrying before the Buddhist period. However, it is certain that the Great

PLATE No.4 Fig.1

ARCHITECTURAL CAPACITY OF STONE (Amber Palace, Jaipur)

PLATE No.4 Fig.2.

STONE HANDICRAFTS FOR ARCHITECTURAL EFFECTS (AGRA)

Ashoka (274-237) organized the quarrying of Vindhyan sandstones near Chunar (U.P) in order to provide a steady supply of stone for buildings during his reign. The rock cut templed at Bhaja, Bedsa, Udaigiri, Ajanta, Ellora, Nagarjunakonda and in South India and elsewhere indicate a great quarrying activity in ancient India. V. Ball[28] writes :-

> "Perhaps the most important quarries in India are those in the Upper Bhanders (the uppermost series in the Vindhyan system), to the south of Bharatpur and Rupbas, in Rajputana and Fatehpur Sikri in the Agra district of the United Provinces, which have furnished building material since before the commencement of the Christian era to the cities of the adjoining plains".

<u>The Ain-i-Akbari</u> written by Abul Fazl in 1590, refers to the red stone which is cut out of the mountains of 'Futtapore' and used for building purposes and it also mentions the prices at which the Emperor Akbar permitted both rough and dressed kinds to be sold.

Even to-day hand hewn and machine dressed stones are largely used in the construction of buildings in many quarry areas of this country. The vast desert tracts of Rajasthan has no other construction material and consequently the maximum number of quarries are to be found in this state. Nearly 20,000 sq. miles of area in Deccan is covered with black cotton soil which is unsatisfactory for brick manufacture. A number of small scale quarries in these areas have been supplementing the demand for construction materials. However, the transition from the use of stone to that of brick is so rapid that the cost -

PLATE 5. Fig.1

STONE BUILDINGS DURING BRITISH RULE

(Central Secretariate, New Delhi)

PLATE 5. Fig.2

PRESENT DAY CONSTRUCTIONS IN STONE

(Supreme Court)

conscious consumer is prepared to use a poor quality brick in preference to a more durable material like stone. This has resulted in a diminution of quarrying activity.

Investigations conducted in several areas, where stone is the main construction material, have established that the economics of building in stone depends largely on the cost of stone itself. Almost all building stone in India is quarried by open cast methods and practically all work is done by numerous small producers who use primitive methods. Three methods are generally used for breaking the rock: hand tools, drilling accompanied by blasting and setting fire in case of granites, gneisses, and charnockites. Cutting is done mostly by chisels. Holes are made along the lines of the intended cut to a depth equal to the thickness of the block to be removed. A scrapper is used to clear the holes. When the bedding planes are close enough the blocks are separated straight away using picks and taking full advantage of the natural joints. Loading and transporting involves removal of the quarried product from the quarry in order to keep the working face clear. The principal stone is carried to the dressing and polishing factory or directly to the despatch yard. Cranes are only occassionally used to raise the stone-blocks or the waste. Indeed, there is little machinery used in the industry.

Most of the quarry centres are not electrified yet and the meagre machinary used is mostly run by oil engine generators. Makrana, the great marble trade centre of India, has nearly 375 factories and quarries. All of these are run individually by large oil engine generators.

PLATE 6. Fig.1

MANUAL DRESSING OF STONE USING CHISELS AND HAMMERS (Dholpur)

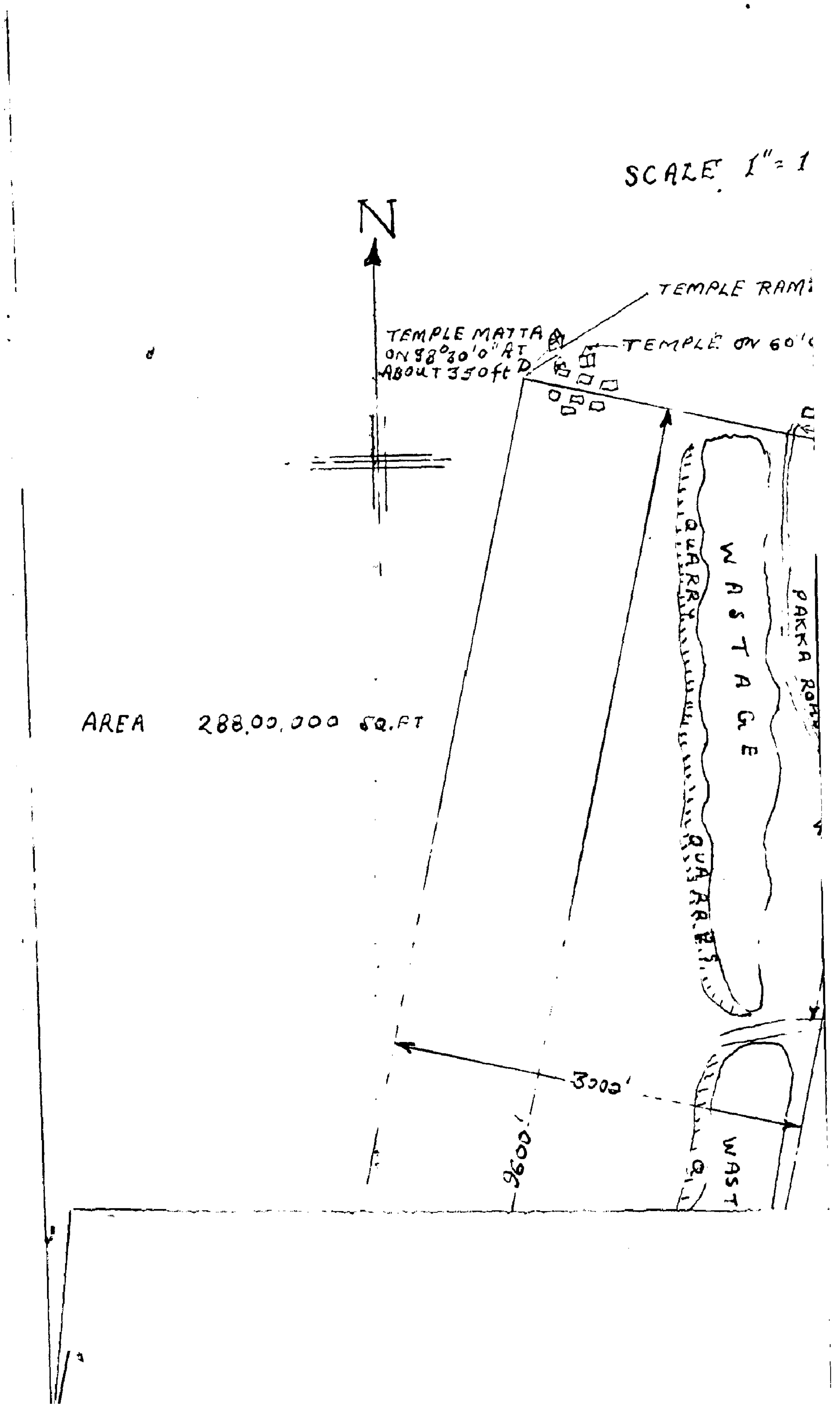
PLATE 6. Fig.2

SIZING A PIECE OF SLATE MANUALLY (KUND)

As the winning technique is crude a large amount of useful stone is shattered and about three tons of stone has to be quarried in order to produce one ton of principal stone. Consequently a high percentage of waste material is produced. This is ultimately transported to a dumping site by an army of regularly paid labour (Fig.2)

Dressing is mostly done manually at the quarry, using ordinary chisels and hammers (Pl.6 Fig. 1&2). Fine dressing and polishing factories are few, and their plants old and antiquated (Pl.7). At most of the quarries polishing is done only by hand using sand as an abrasive (Pl.8 Fig. 1&2). Multiblade saws of iron using ordinary river sand as an abrasive are used in all the marble cutting and polishing factories at Makrana. Locally manufactured low quality carborundum wheels are employed for cutting and sizing the limestone slabs for flooring (Pl.9)

As regards the mineral policy and investment trends, the building stone industry, as defined by the Mineral Concession Rules of 1949, is included in 'Minor Minerals'. It falls under the third category according to the Industrial Policy Resolution of 30th April, 1956, and its development can only take place gradually through the initiative and enterprise of the private sector. The private sector is not fully assured of its existence and there is a great uncertainty about its future status. No incentive is, therefore, available to develope the stone quarries. In view of the short term benifits, the private sector can not be expected to invest heavily in the industry without any reservation of their rights. The industry in India is under-developed



SCALE 1"= 1
N
TEMPLE RAM
TEMPLE MATTA
ON 88°30'0" AT
ABOUT 350ft
D
TEMPLE ON 60'
AREA 288,00,000 SQ.FT
QUARRY
WASTAGE
PAKKA ROA
QUARRY
3000'
9600'
WAST
Q

PLATE No.7

OLD ANTIQUATED PLANTS IN DRESSING AND POLISHING FACTORIES

(Ramganjmandi)

as compared to those in other countries and the discriminate legislative measures enforced by different states considerably retard its growth. The mining legislation, if simplified and effectively controlled through uniform rules and policy, would help and guide the producers in bringing down the costs and unhealthy competition of the quarrying activity in the country.

Problem & Research

From the above description it is evident that the stone industry in past was highly developed but the question now arises as to why there has been no modernization so far in the art of quarrying and sawing natural building stone in India. There are two main reasons besides various small individual factors. Firstly, the quarry masters are neither aware of new methods nor do they have the required incentive and enterprising spirit. Secondly, and more important than the former, is the mechanization which has been evolved and adopted in western countries cannot be directly adapted to Indian conditions. In India the labour condition and their problems are quite different. Here the depreciation of a particular tool which at present is not manufactured in India, is well comparable to the cost incurred on an army of labourers doing the same job. Time is an ignored factor here at present. Research and field trials are, therefore, needed to find new and cheap appliances, though these may not be of exceptional efficiency but should be manufactured locally so that they can be directly adapted to the quarries both for the benefit of labourers as well as the quarry master.

PLATE 8. Fig.1

HAND POLISHING OF STONES (Shahbad, Hyd.)

PLATE 8. Fig.2.

POLISHING BY HAND USING SAND (KUND)

Change Over :

The new methods of quarrying and sawing[29] not only include the use of new excavators and saws, but also the sum total of various improvements in the equipment of the quarries, alongwith the attached workshops and stock-yards etc. It is now known[30] that owing to the size and weight of the stone blocks, handling lifting and ultimately transport contribute largely to the total cost of production and their improvement should, therefore, proceed hand in hand with modernisation in quarrying and sawing techniques. Therefore, improvements must extend to the main layout and general establishment of the quarry and should not be confined to the instruments and equipment alone.

However, new methods involve a change over from hand to machines. Up-to-date saw frames, planning machines, diamond saws, carborundum saws, polishers, stone lathes, stone breakers, crushing rolls, screens, elevators, electric derrick cranes, hand derrick cranes, saw plates and sawing shots, diamond tools and sockets, carbo-saws and polishing rings, masons cutters and chisels and various other tungsten carbide tools etc. are the modern appliances which can be successfully used in various operations of quarrying and sawing building stones. Some of the appliances which can be tried in Indian conditions are discussed below, but their potentiality can only be proved if these are used in India by the quarry owners at various places.

A Machine Designed and Developed For Sawing Flags 'in situ'

The current practice of quarrying flags from the working face is to make holes by drilling along the intended line of cut

PLATE No.9

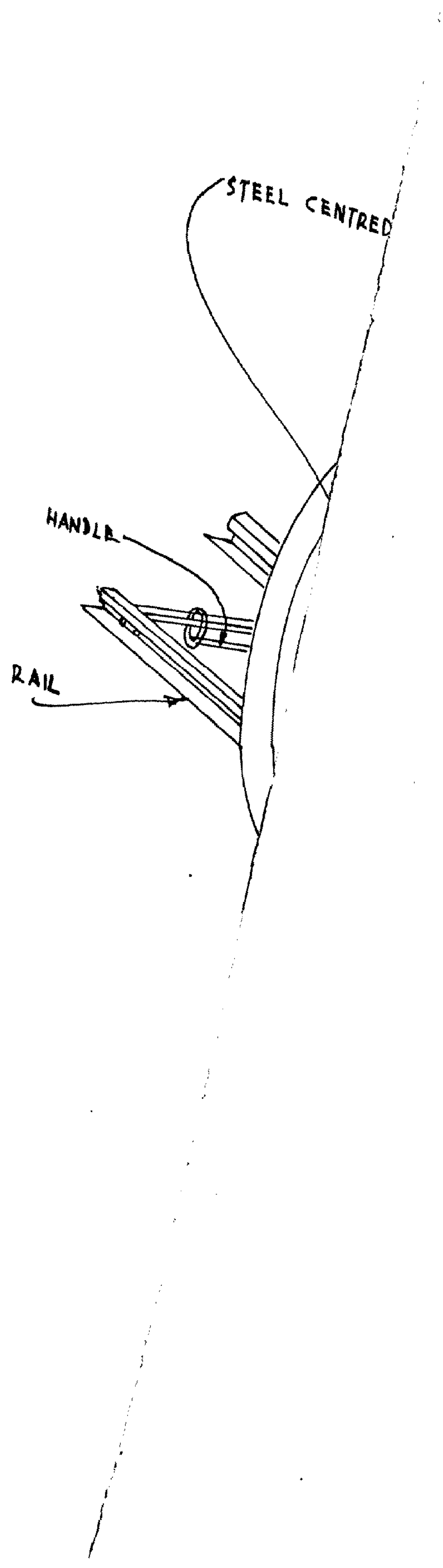
CUTTING AND SIZING OF LIMESTONE SLABS FOR FLOORING

(Ramganjmandi)

then detaching the rock by lever action using hand picks. In case of limestones the slabs are first separated and detached from the rock bed by lifting them up using hand picks. After these slabs are obtained in a haphazard size the intended line of cut is delicately laid over the whole surface from one end to the other. Two hand chisels are then placed exactly below the line at either ends below the slabs. Finally the man slowly jumps over the flag expecting it to be cut along the particular line. Chances are always fifty percent. In half the cases flags and slabs do not follow the line but break along in the direction of some inherent crack.

These methods have got a number of disadvantages. For example, the rate of production is very slow, thin flags and slabs cannot be cut, flags develope cracks and micro-cracks which may be exposed only after it is put in service and the edges have to be dressed again either at the quarry or at the site of construction which entails double expenditure and an unnecessary increase in the initial cost of the stone itself.

Facing all these difficulties, M/s Associated Stone Industries Limited and M/s Kangra Valley State Co. LTD. desired a flag saw to be designed for their use. The proposed saw named here as "FLAG-SAW" w.is functionally like other channelling machines but differed in principle because instead of a series of drills a cutting circular saw has been used. It can be safely handled by unskilled labourers. It is especially suitable for quarries producing limestone slabs and slate tiles for flooring and roofing purposes respectively. Both the wastage and [illegible]


STEEL CENTRED
HANDLE
RAIL

consequently the expenditure in removing that waste is reduced to minimum.

It is thought futile to give detailed mechanical specifications of the whole saw here. Nevertheless a brief account given below when read in conjunction with its figure will give an idea of the whole device. Smaller adjustments can be made depending upon the individual requirements.

The saw (Fig.3) consists of an electrically operated 5 B.H.P. motor and a steel centred carborundum or silicon carbide blade. The blade is screwed to a spindle which is directly coupled through a shaft and an shock absorber to the motor. The saw spindle is kept sufficiently long to allow for no impediments in the clear passage over the stone surface during operations.

The saw assembly unit is mounted on the pedestals with rising and falling motion fitted through a spindle with roller bearings and operated upon by a screw at the top attached to a large diameter hand wheel.

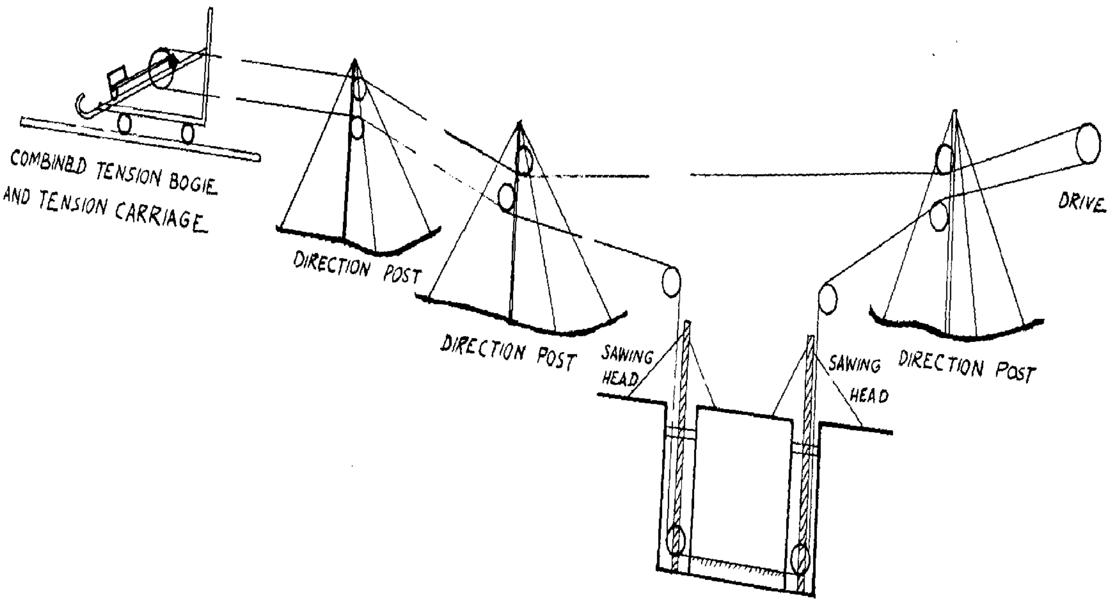
The whole unit described above is a runner being fitted with ball bearings and placed over two rails of special section to avoid side movement.

A simple and adjustable water feed pump is provided. The water is directed at the proper place at a pressure approximately 60 lbs. per square inch . The correct peripheral speed of the blade (which is dependent upon the hardness of stone) is maintained by employing rims of varying diameter. The range of the grits of the abrasives used for the preparation of cutting blades vary between 20 to 100. These blades could be prepared at the quarry itself by mixing the abrasive of the right grit size with phenol-formadihyde resins and then pressing in hydraulic presses. Curing is done at 105° - 110°C in ovens.

The operation of the 'Flag Saw' is very simple and easy. The two rails which can be lifted by hand are kept parallel to the line of the intended cut and the blade lowered to the required depth. The whole unit is then pushed by hand as the blade cuts through the stone 'in situ'. After the first cut, the next cut is made in the reverse direction, thus saving much time in resetting. The whole operation can be conducted by two men with an idle time of 2 to 5 minutes between two operations.

Helicoidal Wire Sawing plants adapted at many quarries in foreign countries can be used for cutting virgin marble, slate or other stones directly out of the quarry face. It can often cut marble upto 6" per hour and limestone 20" per hour and other stones in proportion to their hardness.

For operation at the quarry face a hole or holes are made by hand or by other means available. These holes must be large enough to admit the 'Sawing Heads' (Fig. 4) which carry feed and direction pulleys. 'Direction Posts' are placed at intervals of about 150 ft. (the number varying according to the length of the wire in use) between the sawing heads and the drive and 'Tension Carriage'. The general layout varies with actual site conditions but may be arranged as suggested in Fig. 4. END



LAYOUT OF PLANT SAWING STONE "IN SITU"
NUMBER OF DIRECTION POSTS ACCORDING TO LENGTH OF WIRE IN USE.

HELICOIDAL WIRE SAWING PLANT

FIG. 4

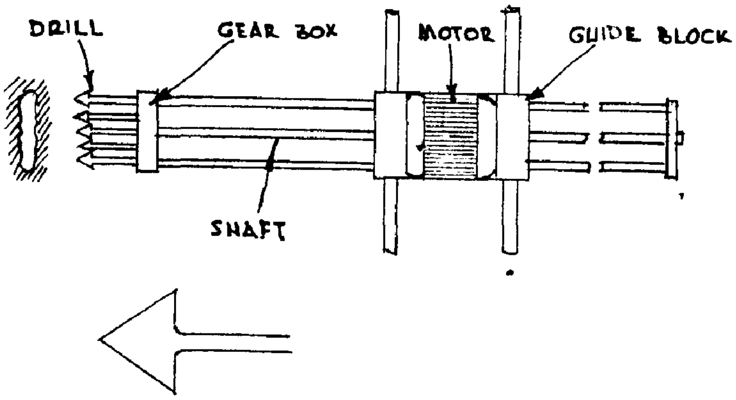
The 'Top Pulley' on the 'Sawing Head' and both pulleys on the 'Direction posts' swivel so that the wire strand can be guided in any direction over a wide range.

The 'Sawing Heads' are made by vertical movements of the cutting edges from 6 ft. to 12 ft. They are held upright by means of steel-guys and turnbuckles. The 'Direction Posts' are supplied with 'Wire Rope' and 'Turnbuckles'. The Combined Tension Bogie and 'Tension Carriage' (Fig.4) controls the tension as the cutting strand cuts into the stone.

Abrasive material is led into the cut, and the sliding pulleys on the 'Sawing Heads' are depressed at intervals by means of the hand chain wheels at the top of the screws. Length of the cut varies from 10 ft. to 100 ft. The power required is approximately 10 to 15 B.H.P. but it depends on many circumstances. Marble is cut 'in situ' at the approximate rate of about 1" to 5" per hour, which varies with the nature of material and length of cut. However, by wire saws, waste as shown in fig. 2 is reduced to minimum. The wire sawing can also be adapted for use in yards for cutting up blocks which are too large to go into saw-frames.

Pneumatic or electric cutters are used in open quarries. Ordinary pneumatic drills can be used vertically in the line of intended cut. Two types of electric cutters of potential utility in India are described below :-

(1) Vertical cutter (Fig. 5) with five drills, tipped with tungsten carbide, turning in alternate direction and working semi-automatically. These drills enter the face



VERTICAL CUTTER WITH FIVE DIRILLS

FIG.5

as they are run by a built-in motor, which is carried on two threaded columns running from the base to the top of quarry. Starting at the base to a depth of 2.30 m., over the full height of the face, say 3.8m. the cuts are made one above the other. The 6 h.p. motor gives a rate of cutting of about 5 meter square per hour.

(2) A cutter working horizontally for cutting slots of a similar depth, but wider. The bottom cut is 0.14 m. sufficiently wide to take the rollers for moving the block. The 8 h.p. engine cuts at about 3½ meter square per hour.

A hydraulic machine is installed to detach the blocks away from the bed and a self-propelled trolly to transport them to the lift shaft. This trolly is designed to move 30 blocks weighing 10-12 metric tons per day working 8 hours a day.

The use of different type of cutters can be made according to the hardness of the stones to be cut*

(1) A battery of 9 steel tubes in the line having their teeth tipped with tungsten carbide, is used specially for hard stones. These tubes cut holes 55 mm. in diameter leaving the cores intact, and forming a grooved slot in the stone. These tubes are carried on a wheeled tubular frame and can be traversed. Each cut is 0.5 m. high and 2 m. deep.

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*A new scale of hardness for rocks used as building stones has been evolved and described. Further the Indian building stones have been classified accordingly. See Chapter VI .

The motor is of 12 h.p. Tubes are fed by water or compressed air depending upon the hardness of the stone.

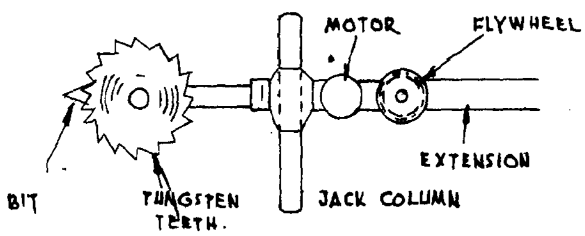
(2) For stone having crushing strength from 50 to 400 kg./cm^2, use is made of a machine (Fig. 6) carrying a drill between two circular saws with tungsten carbide teeth: 250 mm. by 80 mm. deep H-shaped cuts are given by this machine. Between every two cuts the machine leaves a strip of stone intact, so that all the material from the slot is not pulverized. The electric motor is of 2.5 h.p The rate of penetration is from 0.25 m. to 0.35 m. per minute. It takes for two men about 5 minutes to move the frame while the idle time between cuts is about 4 minutes.

(3) For soft stones with a strength of about 50-120 Kg./cm^2 a machine (Fig. 7) is used carrying three rotating cones armed with tungsten carbide teeth, forming a T. This cuts slots 300 mm. by 70 mm. and 2.20 mm. deep. The tool runs on a column, in any position, horizontal, vertical or inclined. Depth of penetration varies from 0.5 to 1.0 m. per minute depending upon the hardness of the stone. Idle time between cuts is about 4 minutes, and two men take 5 minutes to move the frame. The electric motor is of 3 h.p.

Besides those described above, there can be other cutters which can be adapted in India, for example :-

(1) A pneumatic cutter with a rotating pick cutting in either a vertical or horizontal plane.

FACE VIEW



DIRILL BETWEEN TWO CIRCULAR SAWS

FIG. 6

(2) An electric cutter (Fig. 8) with a chain saw working in a vertical plain. This machine is suitable for open quarries when a top layer of stone has been removed. It cuts 20 m. square per day and can be used for underground working as well.

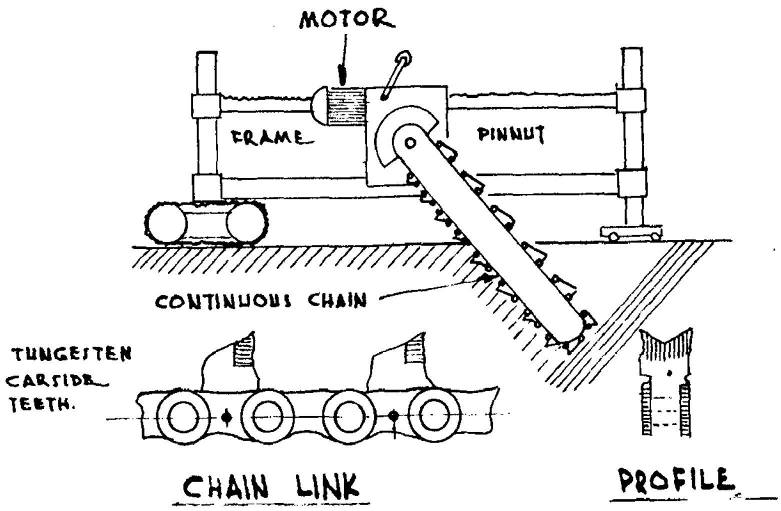
(3) Cutters with chain (Fig. 9) in which the chain consists of a steel cable to which teeth are fixed. The outer ends of these teeth do the cutting while the inner ends are bifurcated to run on edges of the central supporting plate. A series of cuts is made, the cutter traversing on rails and cutting vertically downwards.

(4) Cutters with double action (Fig. 10) are useful because in one operation standard blocks sawn on six faces can be removed. This type has a horizontal shaft mounted on a vertical frame. The cutting tool is a cylindrical milling cutter with tungsten carbide teeth, which cuts slots on the stone at right angles to the face while a longitudinal reciprocating movement clears the debris. The rear cut is made by a circular saw with tungsten carbide teeth, which can be fitted to the end of the milling cutter. In practice two operations are required to quarry rectangular blocks.

SAWING TECHNIQUE :

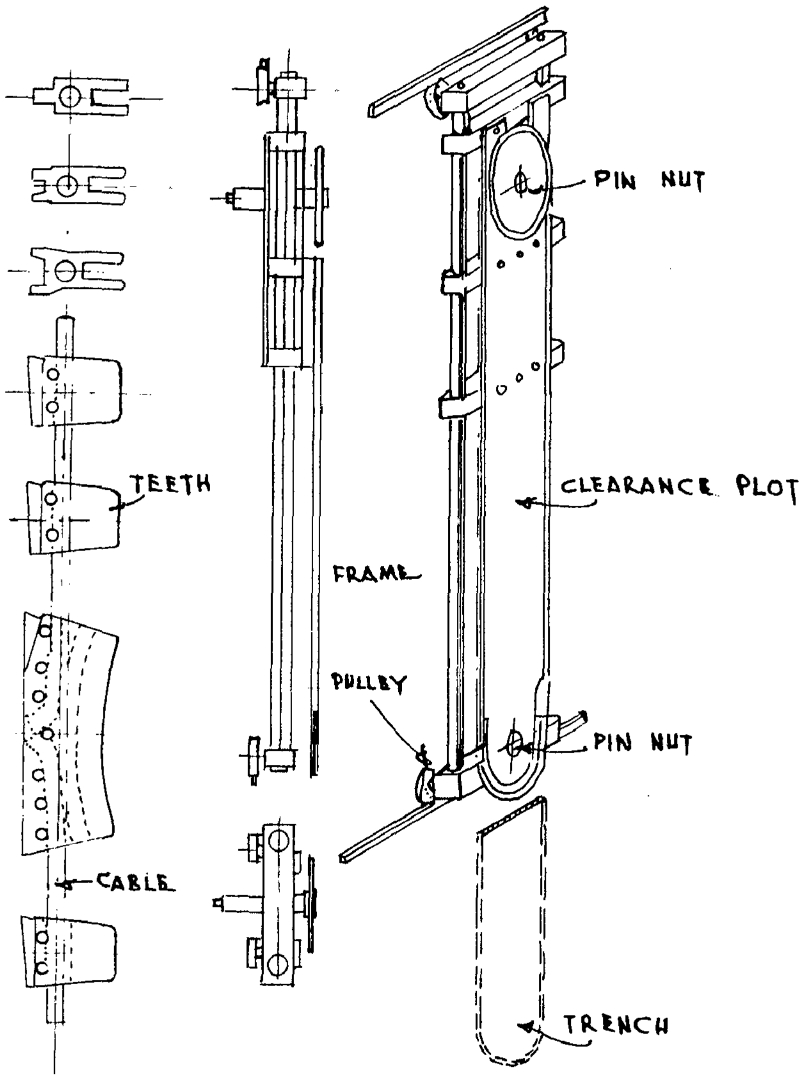
Mechanisation of sawing technique began with the sawing of hard stones which are very slow to cut by hand. For example, it takes about 60 hours to cut 1 m. square of stone of hardness 13*

*As per French specification No. B 10 - 001



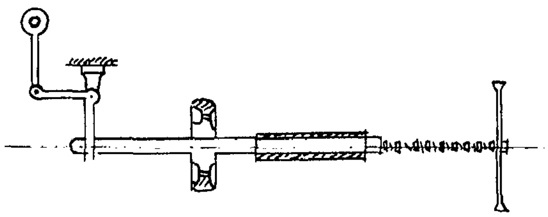
ELECTRIC CUTTER WITH A CHAIN SAW

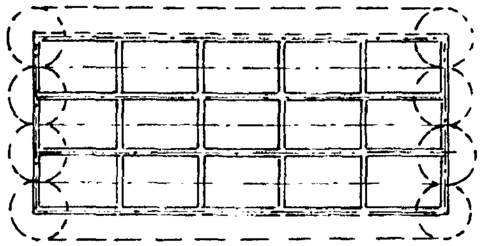
FIG. 8.



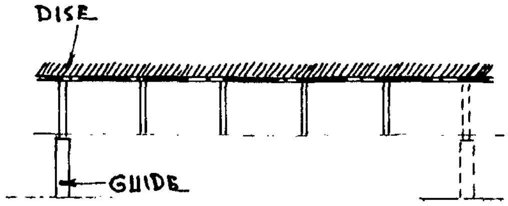
CUTTERS WITH CHAIN

FIG. 9





ELEVATION



PLAN

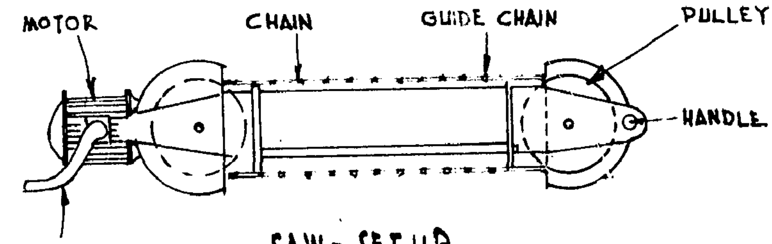
CUTTERS WITH DOUBLE ACTION
FIG. 10

The sawing machines are equipped with a type of wire saw (Fig.11) composed of an endless cable on which are threaded tungsten carbide cutters separated by helical springs 0.06 to 0.08 m. long. The cable runs on two pulleys of soft metal or wood. The number of wire saws can be increased or decreased depending upon the required type of cuts.

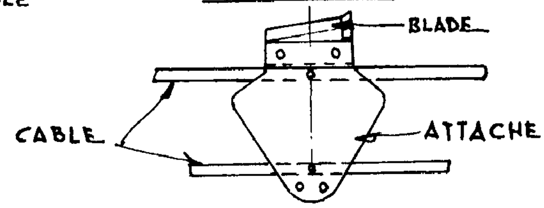
A "Frame Saw" is used for sawing rough blocks which have been cut from the face. It has got a horizontal band saw which makes vertical cuts into the stone. Each band saw is made up of three steel ribbons to which are attached small plates carrying tungsten carbide teeth. These saws cut soft stone at about 1 m. square per minute and hard stone at about 1 m. square per hour.

A wire saw having a 2-Strand cable on which are threaded square plates of tungsten carbide is also backed with mild steel. These plates are 11 mm. square with slightly bevelled edges, and have a round hole in the middle so that they do not come in contact with the cable. The plates are provided with a helical hole so that they can be threaded following the twist in the cable.

The stones may be sawn dry or wet by an endless cable which is driven by a 6 h.p. motor at 240 r.p.m. on two pulleys. The saw assembly is fed down at an automatically determined speed by a 2 h.p. electric motor. The capacity of the machine to cut is 3 m. by 1½ m. The rate of cutting of soft stone is 0.5 m. per minute for a 2 m. block i.e. a rate of 1 m. square per minute.



SAW - SET UP



DETAILS OF A BLADE & ITS SUPPORT

PORTABLE SAW

FIG. 11

ON BUILDING SITE :

The primary problem in the reduction of the initial cost of building in stone, whether of houses or of large government and industrial buildings, is the cost of stone itself. The reduction in the cost of working the stone depends upon the introduction of new machines and mass production techniques.

The mobile type of machines described above are equally suitable for large scale building on public works sites because of the comparative ease with which they can be dismantled and reassembled. However, some lighter types of machines have been designed for sawing stone on the building site. The portable saw shown in Figure 11 weighs only 70 kg. and can be easily handled by two men. It incorporates an endless belt with tungsten carbide teeth, and is pushed down on to the stone. Cutting is at the rate of 0.3 to 0.75 square metres per minute, according to the hardness of the stone. There is a 5 h.p. electric motor at one end.

Modifications in the methods described above are required when siliceous stones and igneous rocks are to be cut. This is essential because these stones are rather coarse grained and the hardness of the particles varies unlike limestones. For siliceous and igneous rocks it is advisable to use a saw with a continuous feed in view of the risk of breakage of the teetxh or seizing up on meeting harder material. For such work the design of machine should permit adjustment of thxrate of feed according to the nature of the stone.

With the adoption of the new techniques of quarrying and sawing, it is hoped that the increased production rate will reduce the price of stone masonry. Building stone which is now considered a luxury material, will be produced at prices which will enable it to compete with the other materials used for this purpose, particularly in the regions where the brick making clays are not available in plenty.

CHAPTER III.

BUILDING STONE QUARRIES IN INDIA

India is fairly bountiful in her resources of building stones and much is reported from time to time in regard to new discoveries of fine building and ornamental stone in several localities. These reports are based mainly on the outcrops of good quality stone, but for an economic exploitation the material should be free from serious flaws and obtainable in large quantities. Further, the subject of availability of building stones in an area is interlocked with the transport facilities in existence. That is the reason why the stones used in any area are mostly the rock types on which the builder could easily lay his hands very close to him. Therefore, any attempt to summarize the existence of available resources of building stone in any country and specially India is an impossible task.

'Building Stones' and 'Road Metals' have always been lumped together for the purpose of information and data available on these so far. Therefore to enumerate and list the building stone alone separately presents a difficult task. However, in this chapter an attempt has been made to enlist the existing building stone quarries in India.

Deposits which are reported to be of future importance and not exploited at present have not been included in the following tables. The information was collected by actual field survey of many quarry centres in the country and through questionnaires issued to quarry owners and state government departments.

Unfortunately, due to the late receipt of replies to questionnaires, in some cases, the names of the operating quarries have just been included at the last moment and the precise longitudes and latitudes could not be indicated. However, to indicate the location 'Talukas' and 'Districts' have been provided instead.

ASSAM

The region being affected by severe earthquakes, the stone structures appear to be easily shaken to pieces. Hence, the use of building stone is not of considerable importance. However, it is being worked at various places. The following are of major importance in this state.

Location of Quarries

Locality	Nature of Rock	Remark
Foot of the Khasi Hills from Therria Ghat south of Cherrapunji to near Chargaon.	Nummulitic limestone.	The famous 'Sylhet Limestone' (really a misnomer as the chief quarries are in the Khasi Hills) The beds vary from 80 to 300 ft. in thickness in the best situated localities[9].
Valleys of the Tuzu Tepe rivers in the Naga Hills	Slates	Locality used in the Naga Villages for Roofing.

Table No.1

ANDHRA PRADESH

The state is richly endowed with limestones and granites. Number of quarries of small size are distributed throughout the state. Tho following are of appreciable size.

Location of Quarries

Locality	Nature of Rock	Remark
Adilabad Taluka.		
Mallapur, Gunmakurd, Yapalgnda, Jainath, Adavillago, Masbrique Ada; Yavasiqundi, Ankunta, Antargaon	Limestone	Takes good polish
Guda Muktinpar, Rampur.		
SIRPUR TALUKA		
Kosini	Limestone	Fine crystalline limestone.
ASIFABAD TALUKA		
Bellampalli	Granite	Coarse porphyritic
KHANAPUR TALUKA		
Rajampet Hamlet of Kondur, Moddipad	Granite	-do-
HYDERABAD WEST-TALUKA		
Maildardevpalli (Pl.10)		
Katedhan; Yusufguda		
Hakimpet; Shaikpet;		

PLATE No.10

GRANITE QUARRY (MAILDARDEVAPALLI) Andhra P.

Upper palli; Kandika Yellapacture Banda; Pogakoni Banda and Kokatpalli, Bellapur, Budvel, Laxmiguda; Mirsafar, Gaganpahad Shivarampalli, Mallapur Rahmatapur, Uppalkalan Malkajgiri, Jallapalli.	Granite	Different shades takes good polish and quarried easily because of joints and fissures.
HYDERABAD EAST-TALUKA:		
Macharam	Granite	Coarse and fine varities.
MEDCHAL TALUKA:		
Rampalli, Yapral Khapda; Grampur, Medchal; Railpur.	Granite	Different shades depending on the predominent felspars.
VICHARABAD TALUK:		
Salabatpur Venkatpur	Limestone	Crystalline
KOLLAPUR TALUK:		
Jatpole Village, Pentavalli, Marod Khurd; Goda Baswapur; Kaber Chette Pahad; Maroor Kalan; Bekkam; Daghda; Welthur; Laxmipalli Koppunur	Limestone	Fine grained limestone of different shades.

KODANGAL TALUK:		
Nandigaon Kalan, Nihoor, Gandla-palli Kodangal	Shaly Material	Of local importance only.
HUZURNAGAR TALUK:		
Baspalodn; Chuitalapalam; Gandlepahad; Peedaired Cillage; Bomatkinta Dondepad Alampur, Rajhunathpalam, Jannapad.	Limestone	Fine grained
MIRYALGNDA TALUK:		
Forest-Block Vazirabad Venkatadripalam, Forest Block,	Limestone	-do-
Chintalapalli, Silkoy, Agha Mathkur Raimadug; Ramalbanda	Granite	Rocks of high ornamental value but quarries not developed.
Darsi and Podili Taluka	Granite	-do-

Bhodan Taluk. Sangarreddly Taluk Guntur Taluk Sattenpalli Taluk	Granite	-do-
PALAND TALUK: Piduguralla, Rentachinta Dachipalli	Limestone	Dark-grey in colour
Yellandu and Manditog in Warangal Distt.	Crystalline Limestone (Archean)	They include white, grey, black and yellow varieties suitable both for general construction and decorative work.
Kurnool, Cuddapah Anantpur, Guntur	Flaggy impure argillaceous limestone.	'The Cuddapah Slabs'
Tandur and Kodangal Taluks (Pl.11 Fig.1&2)	Limestone Slabs	Popularly known as - 'Shahbad - Slabs'
Combum and Markapur in Kurnool Distt. in the Venkatgiri Taluk.	Slates	Famous 'Kurnool Slates'
Kondavidu Hills Guntur Distt.	Charnockites	Known to Civil Engineers as 'Blue Granite'.
Paidipadu Tangellamudi Vernavaram	Khondalites and Gondwana Sandstones.	Much weathered generally.

PLATE No.11 Fig.1

SHAHBAD LIMESTONE SLAB QUARRIES.

PLATE No.11 Fig.2

HUGE DUMPS OF WASTE (SHAHBAD).

Kanigiri	Porphyritic gneiss with white fels-pars.	Used locally
Yerraguntla Jammalamadujn (Cuddapah Distt) Betamcherla (Kurnool Distt)	Calcareous slates.	They form excellent flag stone yielding slabs 1/2 to 4 or 5 inches thick and up to 10 to 12 ft. long and 4 to 5 ft. wide. Used on western coast for flooring.

Table 2.

BENGAL

The state being mostly in alluvial plains, the availability of building stone is scarce and there is some difficulty of getting even the aggregate for making concrete. On the contrary, we find that the stone has been used in the construction of various buildings and the outstanding example is the famous - 'Victoria Memorial' at Calcutta. All most all the important stone supplies have been met from other states of India. Marble used in the 'Victoria Memorial' and other monumental buildings was brought from Makrana (Rajasthan) and other distantly placed regions of the country.

Location of Quarries

Locality	Nature of Rock	Remark
Susumia Hill (23°24':87°2'30") in Bankura Distt.	Quartzite	They were such used in Calcutta for paving floors. Quarries not worked for stone, let for aggregate now.

Coal fields of Bengal :	Gondwana Sandstone	Are being used in the restricted areas of Bengal especially in the coal fields.
Darjeeling	Gneissic rocks.	The main construction material of these areas.
Midnapur	-do-	-do-

Table 3.

BIHAR

The exploitation of the available resources of the building stones in this state is inter-related with the brick industry. The suitable brick clays being available at almost all the places and coal being so abundant in the state, there are not many building stone quarries in the state which require mention.

Location of Quarries

Locality	Nature of Rock	Remark
Shahabad Distt.	Vindhyan Sandstone	Sandstones belonging to Kaimur Series are of good quality and shades vary from cream to pink or light buff.
Kharakpur Hills near Jamalpur in the Monghyr Distt.	Slates	Slates of good quality locally used for floors and ceilings.
Bhitar Dari ($22^{o}41'$: $86^{o}11'$) in Singhbhum	Slates	Little Workings

Table 4.

GUJERAT

In this state, the quarries have been opened in different geological formations. Basalts, sandstones, marbles, phyllites, quartzites, slates, granites and gneisses are quarried at various places.

Location of Quarries

Locality	Nature of Rock	Remarks
Amroli (21°36':71°16')	Basalt	There are many quarries near about Amreli.
Songir (22°6':73°41')	Sandstones	Excellent Sandstones of different shade and textures.
Motipur (Near Bhil van) (22°12'30":73°39')	Marble	The well known Baroda Marbles of Green, White, Pink, brown and Cream coloured varieties.
Jamlugoda and Jhalod Slates	Well cleaved slates and phyllites.	Aravalli system of rocks used locally as flooring and roofing materials.
Nathukua (22°26': 73°35') in Panch Mahals Virjiria (22°2':73°27') in Rewa Kantha.	Hard Gritty Sandstone of Infra-trappean age.	Extensively used in the ancient city of Champaneer.

Many places in Kutch Distt:	Sandstone	From lower portion of the jurassic strata in Kutch.
Dharangadhra (23°0':71°32')	Light coloured conglomeratic sandstone.	Upper Jurassic age?
Baoli (22°56':71'27'30")	Fine grained sandstone.	Used for fine carvings and ornamental objects.
Banda Hill	Calcareous	The well known in building stone of Kathiawar the Porbander Stone.
Virpur (23°45':72°51') Bhulvan (22°12'30"73°39') Bhandrali (22°13'30"73°41)	Granites & Gneisses	Occurrances at a few other places. Rocks of high decoration value.
Baroda (21°42':71°35')	Felsites and acidic traps.	Suitable for general construction only.
Sandia (22°6':73°44')	Siliceous breccia	Hard, red and white siliceous breccia which can be split into thick slabs.
Achali (22°19':73°41')	Flaggy quartzites.	Also at other place near about.
Surajpur (22°25'30":73°40'30"	Slates	Fair quality for roofing.

Sandara (22°4':73°39')	Limestone	These are brecciated in structure and suitable for ornamental work.
Karia Hill (21°14':73°20') Bardaria Hill near Undi (21°40':73°23')	White Trachytic Trap	Used for ornamental purposes in the neighbouring areas.
Pindara (22°15':69°19') in Nawanagar	Limestone	It is a fine grained fossiliferous limestone of orange yellow colour which become red on exposure to the weather.
Bardia (32°12':69°5')	Shell-Limestone	Can be used as a decorative stone also.

Table 3.

JAMMU & KASHMIR

There are no well developed quarries of Building Stones' in the state, though stone is used in abundance. Siwalik sandstones, slates and basalts of Panjal Trap are commonly used in the Jammu Province while in the Kashmir valley bricks and stones are employed in the construction. Granites and crystalline rocks found in main Himalayas are quite suitable for high quality construction but the quarries have not been developed.

The Panjal Trap mainly of basic composition yield fairly good materials for construction.

MADRAS

Granites, charnockites, limestones and sandstones are the main sources of the building stone in the state.

Location of Quarries

Locality	Nature of Rock	Remark
Coimbatore and Nilgiri.	Charnockites and gneisses.	Acidic varieties of charnockites.
Kadanur Zamindari Pirambaher Taluk	Limestone	Locally used only
Coastal Tract of Madura-Tinnevelly	Granite and Gneisses Tertiary, Calcareous grits and tuffaceous limestone.	-do-
Pudukkottai and Tanjore at several places.	Tertiary sandstone	They are of different degrees of hardness.
Chhetinad, Sivaganga and Pattukkottai Taluk	Laterite	Different than those of western coasts laterite quarries in being not so well developed for regular supply.

Table 6.

MADHYA PRADESH

Materials suitable for building purposes occur in great variety and abundance in the state. Geologically the state is occupied by Vindhyan sandstones and limestones in the north, granites and gneisses in the east and south-east and by Deccan Traps in the west, south-west and south. In the heart of the state, the famous Jabbalpur marble fill up the gap. The Vindhyans are capable of yielding inexhaustible quantities of different sandstones. Soils available in the state are mostly black cotton type which is not suited for brick manufacture. The availability of stones in the state for buildings is of great consequence. Small and scattered quarries throughout the state are meeting the demand of staple building material.

Location of Quarries

Locality	Nature of rock	Remark
Sirghora in chhindwara and Paths, Betul district.	White Sandstone	Fine grained.
Pachmarhi	Sandstone	'Grey and buff coloured, coarse grained.'
Chitrakhan (22°26' :76°55'30')	Vindhyan sandstones	
Sajor, Katni, Jukchi		
Chandarpur (Raipur Distt)	Sandstone	
Sikosa and Mahasamund	Thinly bedded limestone.	Dark bluish in colour.

Katni	Limestone	Massive in nature
Damoh	Dark coloured thin bedded impure lime-stone.	Locally used
Bhandara, Baihor, Warasconi and Ramtola Tehsil.	Laterite	Localities in Chattisgarh plain.
Balaghat	Phyllitic schistose Rocks	Used fairly in the neighbouring places.

Table 7.

MAHARASHTRA

Laterite and basalt are the chief building stones in the state. These are exploited at a number of places for local constructions as brick making clays are not available and whereever the bricks are manufactured, the cost is comparable to the blocks of stones.

Location of Quarries

Locality	Nature of Rock	Remark
Kurla near Bombay	Trachytic Trap	Known as 'Kurla Trap'. It is light yellow in colour but contains occasional pyrite.
Ahemdanagar in Idar State	Sandstone (Upper Gondwana)	Excellent Free-stone
Nagpur Viscinity	Basalt	Deccan Trap.
Khandara ($20^{o}18':79^{o}3'$) (Chanda Distt)	Penganga Limestone	
Bhandara	Laterite	Laterite of Chattisgarh region.

Table 8.

M Y S O R E

The state is famous for the export of polished granites and other igneous and metamorphic rocks to foreign countries. It is in this state that the cutting and polishing of hard rocks is most developed.

Location of Quarries

Locality	Nature of Rock	Remark
Karigatta Hills (Mandya Distt)	Diorite Porphyry	Chocklate coloured.
Najowala (Myson)	Norite	
Hanamsagar (15°52':76°6') Raichur Distt.	Sandstone	Belonging to Kaladgi Series
Anadur (Myson Distt)	Felsite	
Kodiyala (Mandya Distt)	Syenite Prophyry.	
Banylon	Granite Augen Gneiss	Used for the construction of 'Mysore Vidhan Sabha'.
Maddur	Gabbro	
Siddalmigapur	Felsite porphyry	Greenish Matrix
Mysore	Hypersthinite	Rock of a great ornamental value because of its peculiar pleasing fabric.
Magadi [illegible]	Pink Granite	Coarse grained

PLATE No.12

DOLERITE QUARRY (Dodbhallabpur)

Doddaballapur (Pl.12) (Bangalore Distt)	Dolerite	Dark coloured.
Bettadabedu (Mysore Distt)	Crystalline Limestone.	Fine grained.
Sriranjapatva (Mysore)	Diorite Porphyry	Light pink
Charunudi Hills	Granite Porphyry	White & Pink
Belgaum Distt. (Pl.13) at various places	Laterite	It is the only staple building material here.
Khanapur ($15^{o}38:74^{o}34'$) South of Belgaum.	Granite Gneisses	
Dharwar Distt. Kanwars Distt.	Hornblendic, chloritic and even hematitic schists of Dharwar system.	Scattered quarries all over used at Dharwar, Gada of and other places.
Aiholi ($16^{o}1':75^{o}57'$) Bijapur Distt.	Sandstone	Yellow and brown sand-stone.
Parvati ($16^{o}2':75^{o}51'$) Alkopur ($16^{o}28':76^{o}6'$)	Sandstone	-do-
Kaladgi ($16^{o}28':75^{o}31'$)	Limestones of Kaladgi Series.	Available in different colours - pink, pur-ple, green, grey and black.
~~Hrgmk~~ Uguni ($16^{o}34':76^{o}32'$) and other places	Limestone.	Grey, drab and cream coloured.

Table 9.

PLATE No.13 Fig.1

LATERITE QUARRY (Belgaum)

PLATE No.13 Fig.2

BLOCKS OF LATERITE (Belgaum)

ORISSA

Number of temples of historic importance are seen in this state where stone has been used in construction. Granite, sandstones and latorite are the chief varieties of stones in common use.

Location of Quarries

Locality	Nature of Rock	Remark
Eastern Ghats and Sambalpur	Granite and gneissic rocks charnockites, garnetiferous gneisses.	Chota Nagpur Facies Eastern Ghat Facies
Near Cuttack	Uppor Gondwana Sandstones.	In Buddhist caves of Kandagiri, it has withstood the weathering for several centuries.
(At few places)	Calcilicate	
Coastal Distt.	Laterite	As a capping over poor quality sandstone.

Table 10.

PUNJAB & H.P.

Slate and ornamental marbles of this state are famous throughout India.

Location of Quarries

Locality	Nature of Rock	Remark
Sardi Glein	Nummulitic Limestone	Fossiliferous limestone
Narhaul in the Mandi & Dalta Hills. (28°3':76°8') Rakandapur (27°59': 76°3')	White, Black and Banded marble.	Famous ornamental stone popularly known as 'PEPSU MARBLE' in the trade.

Islampur ($27^{o}55':76^{o}6'$)		
Prospect Hill (Simla)	Limestone	Compact and Massive
Dharamshala (U.P)	Slate	Soft in nature and much corumpled in quarries.
Nahan	Sandstone	Fairly and locally.
KUND (Pl.14 Fig.1&2) (NEAR REWARI)		Good quality blue slates.

Table 11.

RAJASTHAN

Rajasthan is endowed with a variety of excellent building stones. This 200,000 sq. miles of vast desert tract, a place of important civilization centres, has no other construction material except stone. It is the largest sandstone producing state in the Indian Union and the same sandstone has been used widely from centuries up-till to-day. The famous historical buildings such as the Red Fort at Delhi, the forts and palaces at Agra and Fatehpuri, Jaipur, Amber, Udaipur etc. have all been built from these sandstones. Even to-day, Bharatpur sandstone has found the largest use in Delhi. The sandstones are obtainable chiefly from the Vindhyan System of formations which are exposed at various places. Krinpura granite, quartzites of Alwar, slates of Ajabgarh, Makrana marble of Arrawalli formations,

PLATE No.14 Fig.1

SLATE QUARRYING AT KUND

PLATE No.14 Fig.2

KUND SLATES IN DESPATCH YARD.

flexible sandstones and verigated syenites of Kishangarh are also yielding good quality building stones.

Location of Quarries

Locality	Nature of Rock	Remark
Sawai Madhopur Distt:		
Quarrying Block -		
a) Katri b) Jaggar c) Jhivana d) Karauli	Sandstone	Quarries extend over an area of 8 miles in length and about 2 miles in width. The workable formation which splits well in blocks and beams is about 5 to 10 ft.
Bharatpur Distt:		
Quarrying Blocks -		
a) Near Bund.Barcetta b) Bansi Paharpur (26°55':77°34') c) Rupbas (27°0':73°38') d) Bayana (26°56':77°18')	Sandstone	Slabs, chowkas, flooring tiles. Quarries worked for last several centuries.
Dholpur		
Sri Meathuro (28°32':72°23') Barauli (26°36':77°26') Bari (26°39':77°38') Basari (26°45':77°33')	Sandstone	The famous red stone of Delhi. Quarried at several places.

<u>Kotah Distt:</u>		
<u>Quarrying Block</u> -		
a) Daran b) Mandana c) Modak d) Mokundwara (24°49':76°2') & Kanwar (24°52':76°10')	Sandstone	Vindhyan sandstone of compact variety.
e) Sukot f) Modak g) Ramganjmandi (Pl.15, Fig. 1&2) (24°44':75°50')	Limestone of Nimbahera Stage	The famous 'Kotah Stone'. There are about 100 quarries for slabstone in a flat country streching for about eight miles in length.
<u>Bundi Distt:</u>		
<u>Quarrying area</u> -		
a) Umarthuna (25°24':75°31') b) Satra c) Dhansar d) Karsipur e) Karolidi f) Jakundia g) Rampuria h) Delcta i) Umri	Sandstone	It covers nearly 40 to 50 sq. miles. Beds dip at about 30°.
<u>Jodhpur Distt:</u> 6 miles due west of Jodhpur.	Sandstones	Nearly 1000 small blocks measuring 200'x100' each which have been worked for a long time and are known as 'Fidusar'. The quarries have yielded a large output of roofing slabs and masonry stone and have been famous throughout western Rajasthan. Sizes of roofing slabs vary from 7 ft.

PLATE No.15 Fig.1

LIMESTONE SLABS QUARRIES (Ramganjmandi)

PLATE No.15 Fig.2

VINDHYAN SANDSTONE FLAGS IN DESPATCH YARD
(Ramganjmandi)

		to 12 ft. in length and are about 1½ ft. to 2 ft. wide and 3" to 6" in thickness. There are nearly 360 quarries working at present.
Nagpur Distt:		
Khatu (27°7':74°21')	Vindhyan Flagstone	Much used for carving fine window screens.
Makrana (Pl.16 Fig.1&2) (27°31':74°43')	Marble (Alteration of a superior & inferior beds)	Crystalline Limestone of Railo-Series. Quarries are located close to railway station. The hill runs almost parallel with the railway line for a distance of about 12 miles in the NNE-SSW direction. Nearly 200 quarries are working.
Barmer Distt:		
Barmer (25°40':71°25')	Sandstone	Jurassic or Cretaceous ?
Bhilwara Distt:		
Near Mandalgarh	Sandstone	Nearly 15 quarries working in the area.
Bikaner Distt:		
Dulmera (28°25':73°43')	Sandstone	Extensive number of quarries.
Jaipur Distt:		
a) Bhankri (26°57':76°24')	Schistose Quartzites (Aravalli System)	Beams of 6' to 11' in length, 1' to 1½' in width and about 2" to 6" in thickness.
b) Jasrapura (28°2':75°40') & Amber (26°59':75°53')		-do-

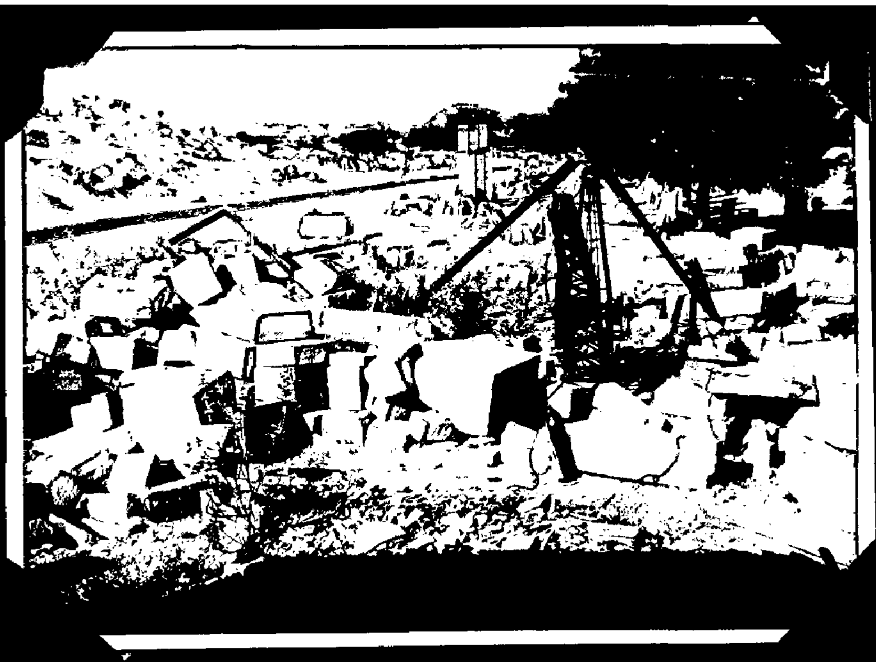


PLATE No.16 Fig.1

MARBLE QUARRIES AT MARKANA.

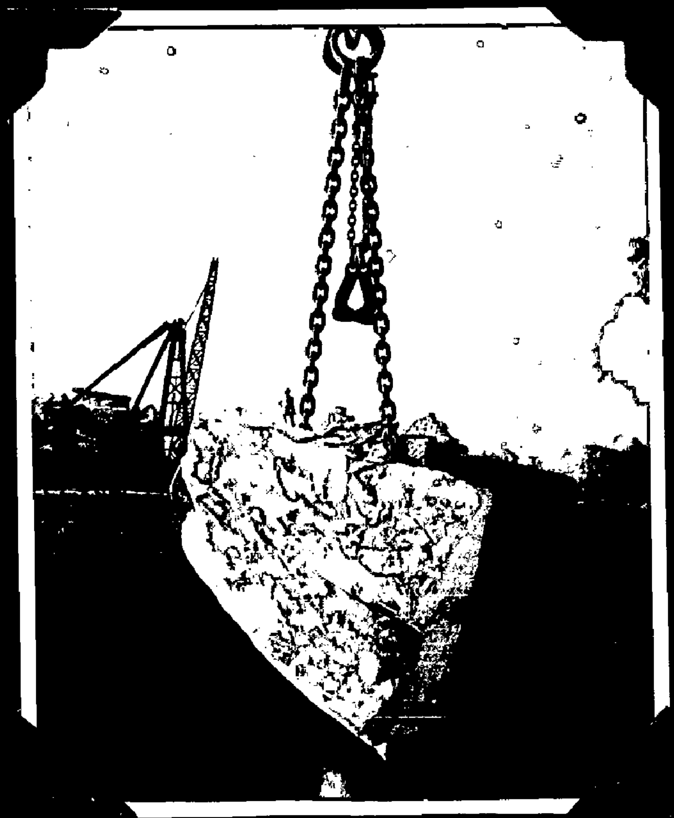


PLATE No.16 Fig.2

CRANES HOISTING MARBLE BLOCKS (MAKRANA)

c) Toda Raisingh (26°2':75°29') & Bilaspur (25°27':75°27') & Tharoli (25°58':75°28')	-do-	-do-
d) Jaipur and Amagarh. (26°51':75°49' 26°50':75°51')	Alwar Quart-zites	It accepts lime mortar well and can be used in masonry without a plaster covering. Such type of work is known as 'Darshan Cheza' locally.
e) Kishangarh		
Sitara (26°32':74°52')	Aravalli Quartzites	Worked by number of quarrymen.
Sursura, Narwar and Tonkra	Marble (White, pink, black, striped, green and spotted)	Contination of 'Makrana Marble range.
f) <u>Alwar Distt:</u>		
Ghat (27°28':76°51') Mandla (27°35':76°55')	Quartzites of Alwar and Ajaibgarh Series	Locally known as 'Berla'. Famous for white crystalline texture. Mostly Chips.
Jhiri (26°50':76°75')	Marble	
Dadampeer (27°34':76°29')	"	

<u>Udaipur Distt:</u>		
Sajjangarh, Goda, Amarjor and 6 miles South of Gogunda.	Phyllites	Roofing slabs
Madar Bhuana	Quartzites	Masonry stones.
Devimata (24°26':73°45')	Marble pink	Raialo Series, Exposed upto Kalakot to a distance of 5 miles having a width of one mile.
Rajnagar (25°4':73°52')	Marble	Quarries worked intermittently on demand.
<u>Chittor Distt:</u>		
Chittor (24°53':74°40') Nimbahero (24°33':74°44') Bhena Senthi, Sawa, Khodip, Jawada etc.	Limestone	Roofing and flooring slabs, masonry stone. Slabs 10' to 12' are quarried. The common sizes are between 12'x12" with thickness varying from 1/2" to 1½" and 36"x24" with thickness varying from 1½" to 3". Nearly 500 quarries.
<u>Jaisalmer Distt:</u>		
Jaisalmer (26°45':70°55')	Yellow shelly limestone containing fossils.	Jurassic age. Takes good polish. Marble quarries 75 to 80 miles from Railway Station Phalodi.

Table 13.

UTTAR PRADESH

Though the state is rich in brick making clays, but a number of quarries are in existence from ancient times. Sand--stones alone are quarried at present.

Location of Quarries

Locality	Nature of Rock	Remark
Mirzapur (25°9' :82°37')	Sandstone	Kaimur Series
Chunar (25°8' :82°57') and other places.		
Fatehpur Sikri Santiadi Pargana	Sandstone	Quarries extend into the district Bharatpur of Rajasthan state.

Table 13.

CHAPTER IV.

EXPERIMENTAL TECHNIQUES & EVALUATION OF BUILDING STONE PROPERTIES

It may be stated at the outset that the problem of ascertaining the field performance of stone as a structural material, is peculiarly complicated and difficult as the diversity of its mineral constituents and factors of genesis have to be considered against different climatic conditions. Though cement, concrete and stone, are very closely related construction materials, but the evaluation of their properties and testing procedures have taken different courses. Test procedures and quality control in cements and concrete are fairly standardized and it is now possible to compare the results obtained by different workers under different conditions of experimentation.

Further stone being a natural material, no two pieces are alike. As a result of these two factors, there is a great deal of variation in the test reports for the same type of stone obtained from the same locality.

Broadly speaking the kind of data which an engineer or architect desires concerning any building stone is to know :

1) Is the stone strong enough for use to which it is to be put ?

2) Will the stone retain its strength, structure and colour after a service of long period of time ?

Hence, any attempt to design the new experiments and the test procedure should, therefore, be directed to answer the above two major questions.

TECHNIQUES AND TEST PROCEDURES FOLLOWED

Determination of True and Apparent Specific Gravity

Various methods of finding out these two properties havo been suggested but the one followed (according to I.S.S.[31] with a fcw modifications) is briefly described here.

Washed and dried specific gravity bottle with stopper was weighed (W_1). 15 grams of stone powder obtained by crushing and passing through B.S. Sieva No. 100 and kept for two hours at 105° to 110°C was put into the bottle and stoppered. It was then re-weighed (W_2). The stopper was then removed and the bottle with its contents was placed in a vacuum desiccator which was evacuated to 74 cm. vacuum. Cooled distilled water was added slowly through the tap funnel until the bottle was full. Later the pressure inside was brought to the atmospheric pressure. The bottle was then kept in a water bath at room temperature for 30 minutes. The bottle was wiped from outside and stoppered and re-weighed (W_3). The bottle was then emptied, washed and dried. It was then filled with distilled water, stoppered and weighed (W_4).

Calculations

$$G_1 = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

where -

G_1 = true specific gravity

W_2 = Wt. in grams of bottle with stopper and powder

W_1 = Wt. in grams of bottle and stopper.

W_4 = Wt. in grams of bottle full of distilled water at room temperature and stopper.

W_3 = Wt. in grams of bottle with stopper plus stone powder plus water to fill the bottle at room temperature.

APPARENT SPECIFIC GRAVITY

The test piece was dried at 105° to 110°C for 72 hours, weighed (W_5) and placed in a vacuum desiccator. The pressure was reduced to 74 cm. vacuum. Pre-boiled and cooled distilled water was admitted into the vacuum desiccator through the tap funnel until the test piece was completely covered. The test piece was left overnight in this state. It was then weighed in water (W_6), wiped with a damp cloth and then weighed in air (W_7).

Calculations

$$G_2 = \frac{W_5}{W_7 - W_6}$$

where :-

G_2 = apparent specific gravity.

W_5 = Weight of dried test piece.

W_7 = Weight of the surface dried test piece.

W_6 = Weight of the test piece in water.

DETERMINATION OF POROSITY :

From the above determination, the porosity was then calculated from the following formula using apparent and true specific gravity data -

$$\text{Porosity} = \frac{G_1 - G_2}{G_1} \times 100$$

Microporosity was determined[32] by the microscopic examination of thin sections.

DETERMINATION OF WATER ABSORPTION

The method described below is a slight modification of the I.S.S[33].

Six test pieces of 3 cm. cube were prepared from the sample. They were dried for 48 hours in an oven at 110° - 115°C. After cooling the same down to room temperature, the test pieces were weighed (W_1). The dry specimens were completely immersed in water at 20° to 30°C and kept for 24 hours in it. After 24 hours, the specimen was wiped off with a damp cloth and the specimen weighed (W_2).

The specimens were again returned to the vessel filled with water immediately after weighing. The water was heated to boiling in approximately one hour, and the boiling was continued for five hours and then allowed to cool to 20° to 30°C by natural loss of heat within a period of 20 hours approximately. Specimens were removed, the surface water wiped off with a damp cloth and the specimen weighed (W_3). The weights of each specimen was completed within a span of three minutes after its removal from the tank (Pl.16).

Calculations were made as below :-

a) Absorption, percent by weight, after 24 hours total immersion $= \dfrac{100\,(W_2 - W_1)}{W_1}$

b) Absorption, present by weight, after 5 hour immersion in boiling water $= \dfrac{100\,(W_3 - W_1)}{W_1}$

where

W_1 = Weight in grams, of the dry specimen.

W_2 = Weight, in grams of the surface dried specimen after 24 hour immersion in cold water.

W_3 = Weight in grams of the surface dried specimen after 5 hour immersion in boiling water.

The average of all the six results obtained was taken as the water absorption of the particular specimen.

CALCULATION OF SATURATION CO-EFFICIENTS

From the data on absorption percent saturation co-efficient was determined as :-

$$K = \frac{W_2 - W_1}{W_3 - W_1}$$

where K is the saturation coefficient

W_2, W_1, W_3) have the same notations as in the case of water absorption test.

PETROGRAPHIC EXAMINATION

The rock samples were examined macroscopically and microscopically for their colour, structure, texture and mineral constituents. Thin sections of approximately 30 μ were prepared from the fresh samples as well as from those which were left after salt crystallization tests. Lake-side '70' was used as the impregnating material in case of certain sandstones, mud-stones, phyllites, laterites and other friable rocks. The material was sometimes coloured by using organic dyes, in order to study the pores and the pre-structure.

The planimetric analysis of materials whenever required was done using the 'Integrating Stage' with 'Panphot Polarizing Microscope'. The grain size measurements were done by using 'Leitz Screw Micrometer EYE PIECE' (Pl.17 Fig. 1 & 2).

Surface examination of the specimens (polished and unpolished) was undertaken by using the 'Ultropak' incident light illuminator consisting of the housing with fixed ring mirror oriented at one angle of 45° and interchangeable UO objectives with vertically adjustable ring condenser. The light is guided to the specimen by way of the ring mirror through the annular condenser, which surrounds the objective concentrically.

Detailed examination of optical properties of the minerals and of the cementing medium was done by using 'Universal Stage UT4' (with 4 rotary movements with pair of segments $n_D = 1.55$).

In order to produce a better contrast with associated minerals coloured lights (Green, Blue, and Yellow) either transmitted or incident were used by introducing coloured filters.

METHOD OF TEST FOR DURABILITY

The method briefly described below is more or less on the lines of I.S.S.[34]. Four sample test pieces of 4 cm. cubes of each rock type were used for conducting the test. The samples

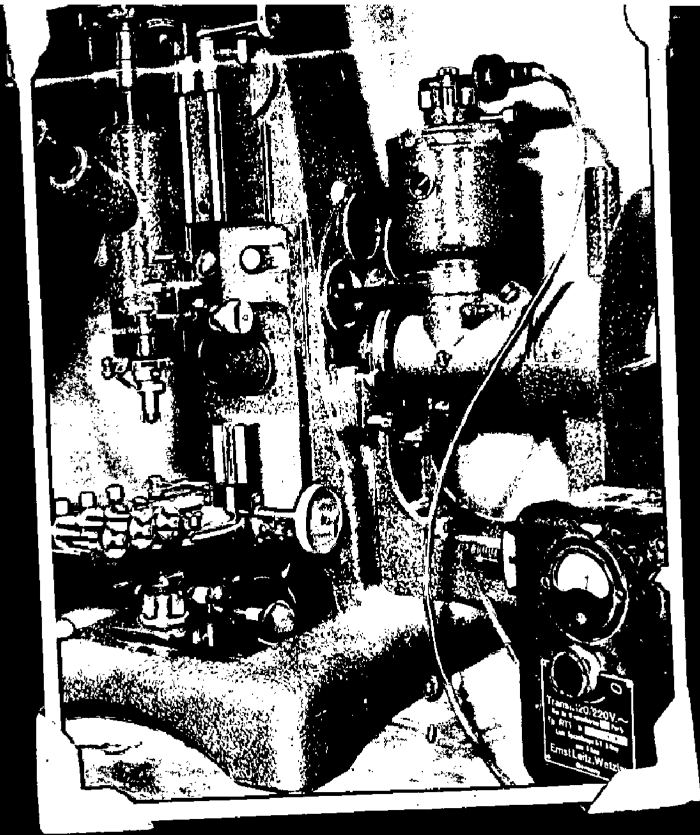


PLATE No.17 Fig.1

PLANIMETRIC ANALYSIS OF MATERIALS

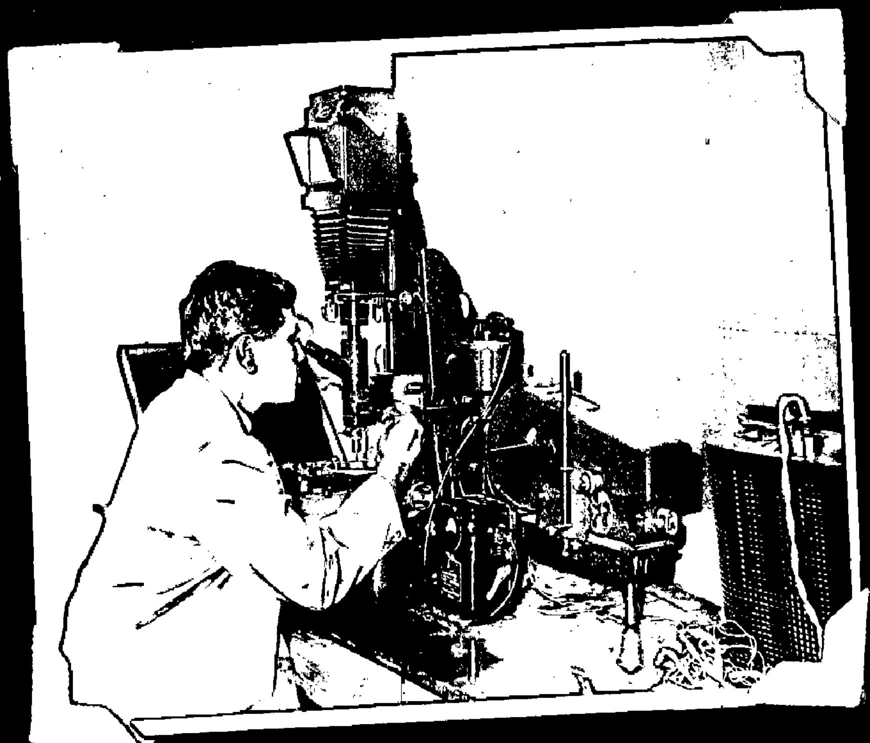


PLATE No.17 Fig.2

GRAIN SIZE MEASUREMENTS BY 'PANPHOT'

were dried for 72 hours and weighed. They were then suspended in solution of 14% Na_2SO_4 10 H_2O (sodium sulphate decahydrate) with a density of 1.055 grams/cc, for 4 hours at $27^o \pm 2^oC$. Then the pieces were air dried for half an hour and then dried overnight in an oven at 105°C. Next morning the samples were cooled down to room temperature for three hours and the cycle of operations repeated. The test was continued to complete 30 cycles. The test pieces were weighed after every five cycles and the change in weight due to disintegration noted. The stone pieces were examined during the course of the test for the development of cracks and spalling (Pl.18 Fig. 1 & 2).

Calculation

If W_1 is the original weight of the specimen and W_2 is the weight of the specimen after completion of 30 cycles of the test, the change in weight shall be reported as equal to :-

$$\frac{W_1 - W_2}{W_1} = x \ 100$$

DETERMINATION OF COMPRESSIVE STRENGTH

Six test pieces of the size of 5 x 4 in. x 3 in. and free from seams or fractures were cut from the sample with diamond saw as per I.S.S.[35] (Pl.19).

The load bearing surfaces were made to true, parallel and perpendicular planes by using carborundum powder of various grits as abrasive material. The direction of the rift and the load bearing surfaces were marked on each specimen. Three samples were tested parallel to and the other three perpendicular to rift

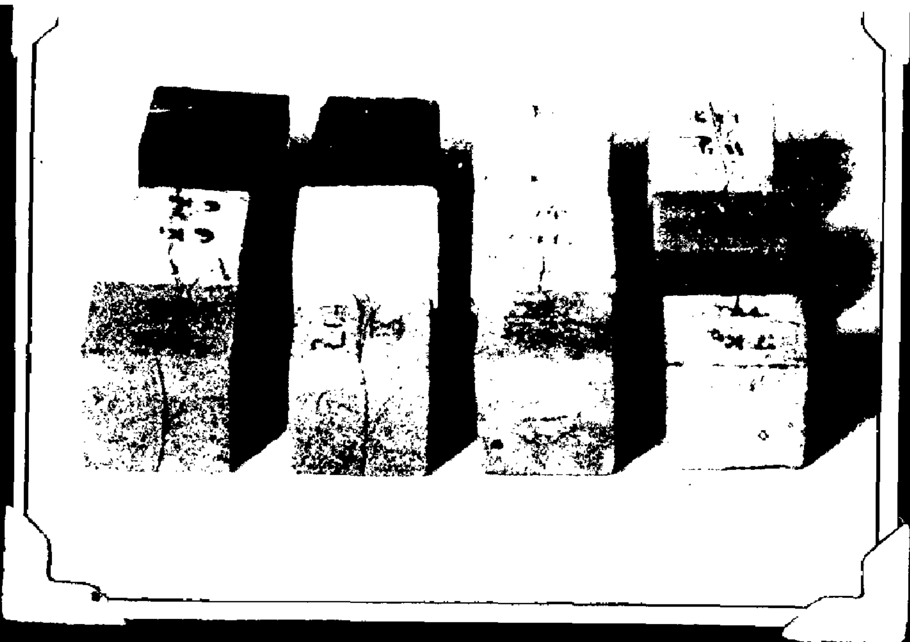


PLATE No.18 Fig.1

STONE SAMPLES BEFORE TEST FOR DURABILITY.

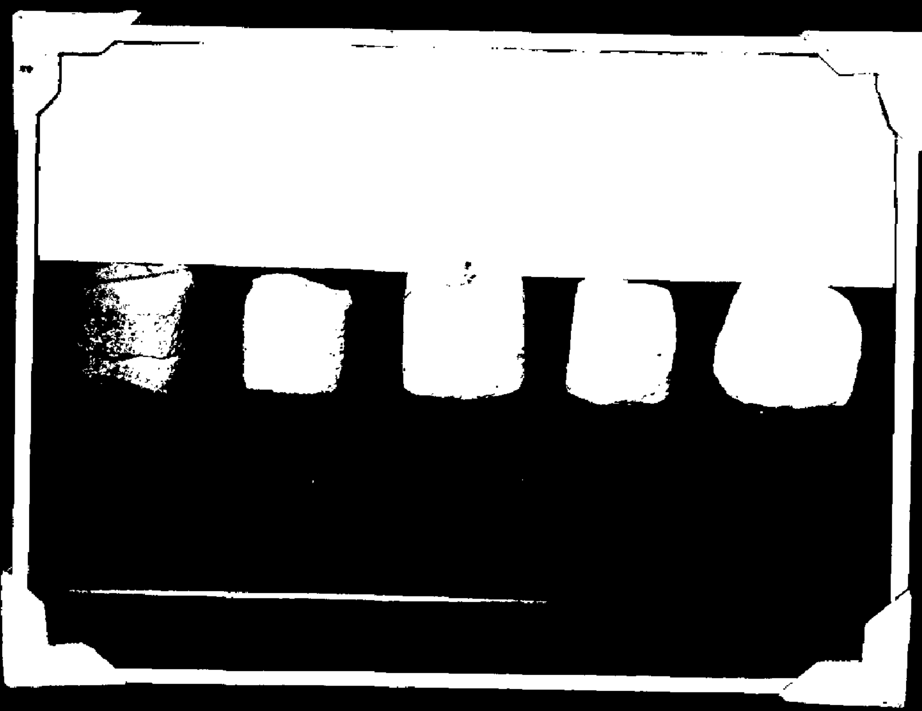


PLATE No.18 Fig.2

STONE SAMPLES AFTER TEST FOR DURABILITY.

planes. Specimens were dipped in water kept at 20° to 30°C for 24 hours prior to testing the specimens.

Apparatus :

The machines were equipped with two steel bearing plates with hardened faces. One of the plates normally bearing the upper surface of the specimen was fitted with a spherical ball the centre of which coincided with the central point of the face in the plate. The other compression plate being plain rigid bearing blocks. The bearing faces were larger than the normal size of the specimen to whih the load is applied.

Test Procedure :

The load was applied without shock and increased continuously, till the resistance of the specimen to the increasing load gave way and no greater load could be sustained. The appearance of the stone and any unusual features in the type of failure was noted (Pl.20)

Calculations.

$$C = \frac{P}{A}$$

where C is the compressive strength in lbs/sq.in.

P is the maximum load supported by the specimen just before failure in pounds.

A is the area of the bearing surfaces of the specimen in sq. inches.

DETERMINATION OF THE TRANSVERSE STRENGTH

Three test pieces of the size of 8 x 2 x 2 inches were prepared

PLATE No.19

PREPARING STONE SAMPLES BY DIAMOND SAW (C.B.R.I)

(I.S.S.[36]) and accurately measured at the centre section. Each piece was soaked in water at 20° to 30°C for 24 hours, prior to testing and the wet specimen was tested. Direction of the rift plane was marked.

Test Procedure

The test pieces were supported on two self aligning bearers A & B (Fig. 12) each 4 cm. in diameter, 15 cms. apart from centre to centre. Bearer A is supported horizontally on two bearer screws C which carried hardened steel balls D concentric with the bearer. Bearer B is supported on one such bearer screw and ball. The load was applied centrally at a uniform rate, through a third bearer E which is also 4 cm. in diameter and is placed in midway between the supports upon the upper surface of the specimen S and parallel to the supports.

Calculations

$$R = \frac{3\,WL}{2\,bd^2}$$

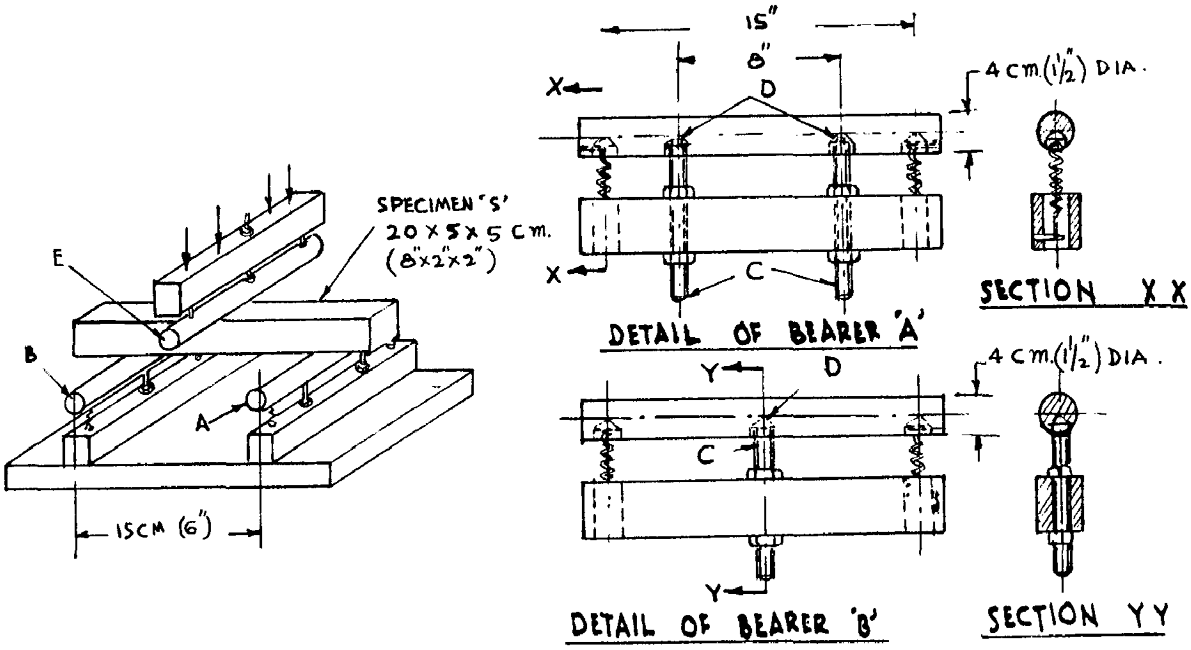
where R = transverse strength in Pounds per sq. in.

W = Central breaking load in Pounds.

L = Length of span in inches.

b = average width in inches of the specimen at the mid section.

d = average depth in inches of the specimen at the mid section.



SELF ALIGNING BEARERS

FIG. 12

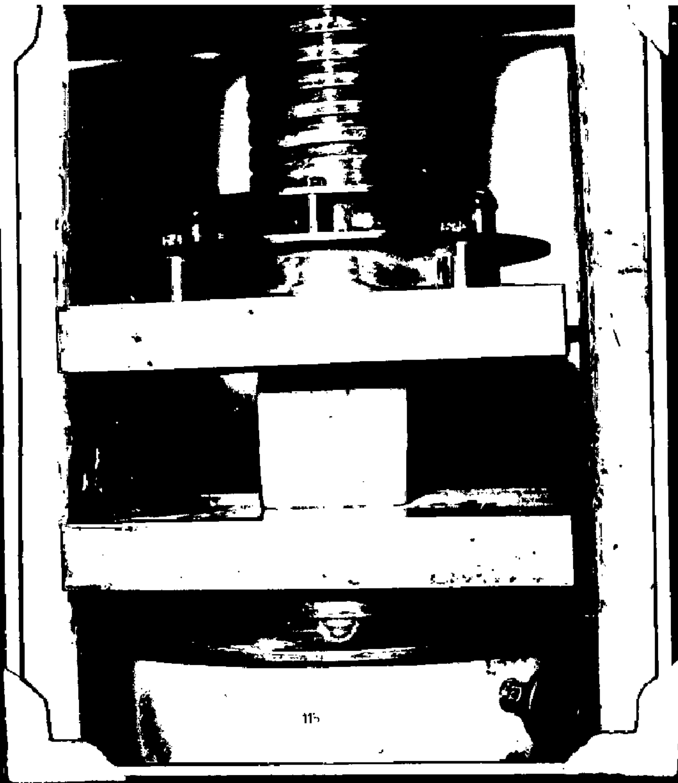


PLATE No.20 Fig.1

A STONE CUBE UNDER TEST FOR COMPRESSION (CBRI)

PLATE No.20 Fig.2

STONES UNDER TEST FOR WATER ABSORPTION.

DETERMINATION OF THE SHEAR-STRENGTH

As per I.S.S.[37] test pieces in the form of slabs 1½ inches in thickness, 4 inches in width and 4 inches in length were cut parallel and perpendicular to rift planes from the original samples with diamond saw and the load bearing surfaces finished to as nearly true and parallel plane as possible by using carborundum powder.

Dutton punching shear device in conjunction with the two testing machines used for the determination of compressive strength was used.

The pieces were carefully centred between the upper and lower plates of the punching devise so that the measured section of the specimen was under the plunger. The upper plate was carefully lowered to contact the specimen.

The punching device of the machine was then centred with the centre of the spherical bearing block in contact with the centre of the top portion of the plunger of the shear device. The speed of the moving head of the testing machine during the application of the load was kept very gradual.

Calculations.

$$S = \frac{W_t - W_1}{DT}$$

where S = shear strength in Pounds per sg. inches.

W_t = total, max, load in pounds indicated by the testing machine.

W_1 = initial load in Pounds required to bring the plunger in contact with the surface of the specimen.

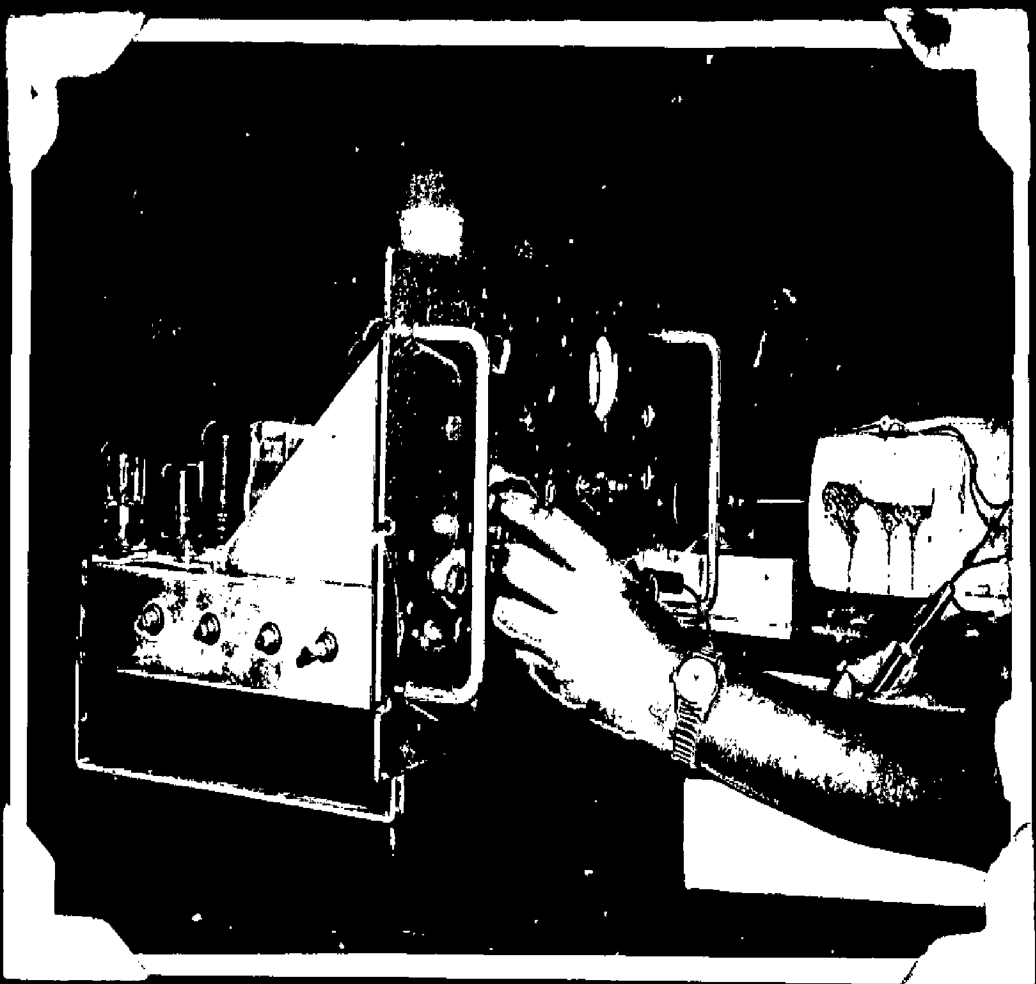


PLATE No.21

SONIC TESTING EQUIPMENT (C.B.R.I)

D = diameter in inches of the plunger and

T = thickness in inches of the specimen.

DETERMINATION OF DYNAMIC MODULUS OF ELASTICITY

The sonic tester designed[38] for the laboratory determinations of the dynamic modulii of elasticity and the logarithmic decrement of common building materials was used. With this instrument resonant frequencies in the transverse modes of vibration of the specimens was determined. The frequency response curve (amplitude versus frequency) at the resonant frequency was obtained. The dynamic modulus of elasticity was calculated using equation (1) given below.

The apparatus shown (Pl.21) is mainly an electronic device, which consists of

a) Driving circuit

b) Pickup Circuit

c) Indicating Unit

d) Specimen holder

The relationship between the dynamic modulus of elasticity and the transverse resonant frequency is given by the equation :

$$Ed = CW\,(nt)^2 \qquad \ldots\ldots \qquad (1)$$

where C, is a factor depending upon the shape and size of the specimen, mode of vibration, and poissons ratio, and is given by :-

$$C = \frac{0.00145\, L^3 T}{bt^3}$$

where

W = is the weight of the specimen in pounds (lbs)

nt = resonant frequency in transverse mode of vibration.

L = length of the specimen in inches

T = 'Goens Correction factor' which depends on the ratio of radius of gyration and length of the speciman (K/L)

b = breadth of the speciman in inches.

t = thickness in the direction of vibration in inches.

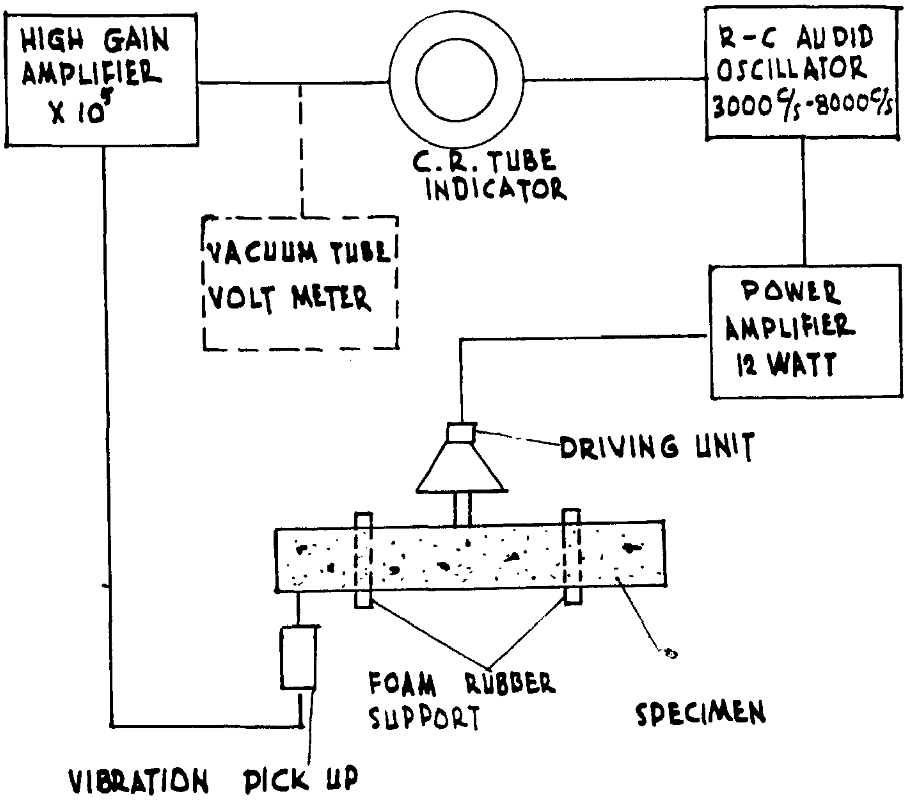
K = radius of gyration for rectangular prismatic specimen K = t/3.464.

In the transverse (flexural) mode of vibration two nodal points, located at 0.224L from each end are formed. The centre and the rear form as antinodes. In order to allow a free mode of vibration, the specimens are supported at the nodal points and the exciter is located at the centre. The arrangement of supporting and the positions of the exciter and the pick up are illustrated in the figure 13.

The dynamic modulus Ed is calculated for this frequency 'nt' by the equation given above. This method confirms to the ASTM C215-4TT.

<u>Ultra Sonic Test</u>

Ultra Sonic phase velocities through the specimen are also determined by measuring the time taken to travel from one end to the other, electronically. The equipment used is shown in Pl.22.



SCHEMATIC DIAGRAM FOR TRANSVERSE RESONANT FREQUENCY DETERMINATION.

FIG. 13

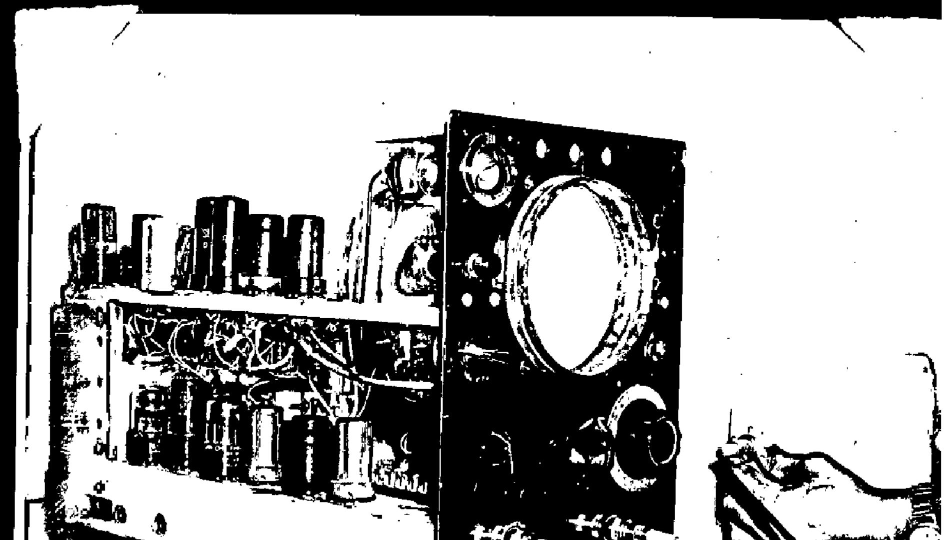


PLATE No.22

ULTRA SONIC TESTING EQUIPMENT (CBRI)

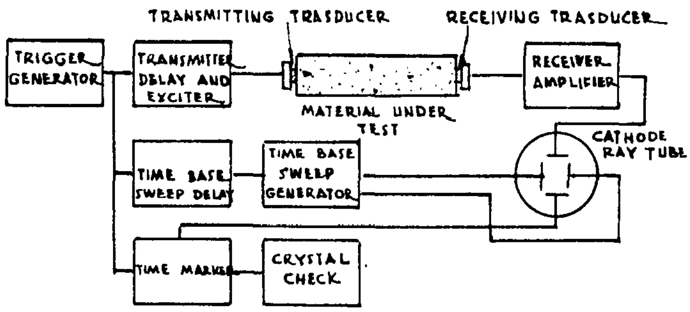
Circuit arrangements of the ultrasonic apparatus for transmission method is also shown by the schematic diagram given below in Fig. 14.

The functions of the different circuits are as follows :

The trigger generator produces a negative rectangular pulse at a repetition frequency of 50 pulse/second from the leading edge of which the transmitter, and time marker circuits are all triggered. The transmitter variable delay unit generator is a rectangular pulse which can be varied over a range 10 micro-seconds and triggers the transmitter exciter. An ultrasonic pulse, consisting of a train of longitudinal waves, result from the shock excitation of a piezoelectric crystal transducer which is coupled to the material under test by a thin film of oil. A similar piezoelectric transducer is used to receive the ultrasonic pulse after travelling through the material. The received signal is led through a high grain amplifier to the vertical deflection plates of a cathode ray tube. The time base sweep delay and the time marker circuits enable to measure accurately the time taken by ultrasonic pulse to travel through the known length of the material. From this data the wave velocity (VL) of an ultrasonic pulse in the medium is calculated.

The velocity of an ultrasonic pulse in a medium will depend on the modulus of elasticity and density of the material and the relation is given by ~~equation~~ the following equations :

$$VL = \sqrt{\frac{E\ (1 - \sigma)}{\rho(1 + \sigma)\ (1 - 2\sigma)}}$$



SCHEMATIC DIAGRAM OF THE ULTRASONIC PULSE TESTER.

FIG. 14

where

VL is the ultrasonic pulse velocity in ft/sec.

E is the Modulus of elasticity in lb/sq.in.

ρ is density in lb/cu.ft.

σ is the poisson's ratio.

The above equation holds good for a medium of infinite dimensions.

In a finite solid, the primary or axial waves set up lateral waves which reflect back from the boundaries and cause destructive interference with the primary waves and reduce the velocity of the primary wave. Thus the formula reduces as :-

$$V_L = \sqrt{\frac{E}{\rho}}$$

Using this equation the Modulus of elasticity for the stone specimens have been calculated and the results are given in Table No. 74 and 75.

CONCRETE AGGREGATE TESTING PROGRAMME

To study the influence of different rock forming minerals in the aggregates and the concrete, tests have been carried out on Indian minerals and rocks ~~respect~~ seperately. The following minerals were used as aggregates :

1) Quartz (Rose, Senoky, Milky)
2) Flint
3) Quartzite
4) Chert, Chalcedony, opal
5) Magnesite
6) Hematite

7) Albite

8) Orthoclase

9) Labrodorite

10) Orthoclase

11) Microcline

The following rock types were used as aggregates to study their influence on the concrete (Chapter XII).

1) Granite

2) Basalt

3) Sandstone

4) Limestone

5) Marble

6) Dolerite

7) Phyllite

8) Syenite

9) Gabbro

Samples were crushed and passed B.S. Sieve Nos. 100, 52, 14, 7, and 3/16 in; 3/8 in. 3/4 in. size mesh. The graded aggregates were then prepared.

The mortar mix was prepared by mixing one volume of portland cement to four volumes of aggregates. The water cement, ratio was 70 by weight. Approximately a constant slump as determined on a standard flow table with a cone 3 inches was obtained. It has been observed that Chert, Magnesite and Barite required 0.75. 0.82 and 60 water/cement ratio to produce the same slump.

Six briquets were prepared from each specimen and stored for 24 hours in the molds in a damp closet. Some briquests were also autoclaved at 150°C for 24 hours and broken after cooling. Two extra briquets were stored in water and the two at room temperature.

Petrographic examination of the specimen of aggregate was undertaken by preparing thin section of approximately 30 μ. Internal structure, texture and fabric of the specimen were noted and compard with each other and also with the results of tests conducted on concrete cubes in each case. Pore characteristics and fissuring was observed in thin section study.

Hydrated cement - concrete cubes especially prepared from the reactive aggregates were examined. Petrographic examination of deteriorated concrete was also taken by preparing polished section and examining these by 'Ultropak' with a view to study the alkali aggregate reaction and also to distinguish other types of break down resulting from other type of cement aggregate reaction.

For studying the affect of aggregate properties on the flexural and compressive strength of hardened concrete, briquets were prepared with 10 different types of coarse aggregates from different rock types as given in the table No.14.

TABLE

Sample Index Number	Rock Type	Source in India	Condition
5 GR	Granite	Bangalore	Crushed
2 BS	Basalt	Nagpur	do
4 QZT	Quartzite	Delhi	do
16 SST	Sandstone	Dholpur	do
LM.ST	Limestone	Ramganjmandi	Crushed supply
MB.	Marble	Makrana	Crushed
DL	Dolerite	Dodballabpur	do
3 PH	Phyllite	Udaipur	do
SY	Syenite	Mandya	do
GB	Gabbro	Muddur	do

Table No.14.

Sand was used as fine aggregate in all the concrete mixes.

Aggregate properties such as water absorption and specific gravity were measured along with the stone testing programme. Angularity was measured by Shergolds method[39] according to which the angularity is measured by the ratio of voids in 3/4 - to 1/2 in. fraction of the aggregate after compaction. The "angularity number" is the percentage of void less 33.

Flakines index of the aggregate was measured in accordance with B.S. 812. It is expressed as the total weight of the different size fractions of the aggregate as a percentage of the total weight of the sample tested.

Average crushing value of aggregates was obtained by subjecting 1/2 in. to 3/8 fraction of coarse aggregate to a specified compressive load. The weight of aggregate passing B.S. sieve No. 7 was then expressed as percentage of the total.

Surface texture of aggregates was determined by the method used by Wright[40]. Aggregate particles of 3/4 in size were impregnated in a test tube by using Lakeside 70. Later, the thin sections were prepared by the normal method of preparing rock sections. Grinding was normally continued to produce a section of about 0.001 inch thick.

Panphot - polarizing microscope, photo relfex housing was fitted with ground glass screen. A magnification of about 125× was adjusted by putting 10/0.25 objective and 10X eyepiece. Later the actual profile was traced by using 'Camera Lucida'.

The flexural and compressive strength of concrete were also determined in accordance with B.S. 1881[41]. These were calculated to the nearest 5 lb/sq.in.

For compression 4 inch cubes were prepared and the compressive strength of the specimen was calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area. The results have been given in chapter No. XII.

CHAPTER V.

PHYSICAL & CHEMICAL PROPERTIES OF INDIAN BUILDING STONES

In proceeding pages the results of the physical and chemical tests undertaken on Indian Building Stones have been tabulated and discussed. During past few years tests have been undertaken by various engineering projects on these physical properties of a few building stones from Indian sources, but these tests related only to those stones which were anticipated to be utilized for a particular project.

Surprisingly the evaluation of the physical and chemical properties on Indian Building Stones from the working quarries has not been attended so far. Data on those properties is required for the purposes of engineering and architecture. Results presented in the annexed tables have been carried out to fill up the gap and in doing so attempt has also been done to discuss and interpret the results in a way so that it could be of value to those care for a scientific approach towards these natural materials.

The method of presentation is not quite good

SAND - STONES

PHYSICAL PROPERTIES

A. Specific Gravity & Wt./Cu.ft.

ample ndex umber	Locality	Apparant Specific gravity.	True Specific Gravity	Wt./Cu.ft. in Lbs.
SST.	Shahbad Distt. (Bihar)	2.673	2.731	170.6
SST.	Songir (Gujerat)	2.256	2.658	160.5
SST.	Nathkua & Panch-Mahals etc. (Gujerat)	2.582	2.657	162.2
SST.	Kutch Distt.	2.171	2.647	157.9
SST.	Dharangadhra (Gujerat)	2.054	2.654	145.9
SST.	Barda Hill	2.233	2.436	155.8
SST.	Pudukkottai & Tanjore	2.494	2.573	158.3
SST.	Singhora & Betul (M.P)	2.360	2.512	164.1
SST.	Panchmarhi (M.P)	2.029	2.170	137.5
SST.	Chirakhan (M.P)	2.285	2.401	145.9
SST.	Ahmadnagar (Maharashtra)	2.314	2.647	139.6
SST.	Hamamsagar (Mysore)	2.532	2.671	159.1
SST.	Aiholi (Mysore)	2.033	2.157	135.6
SST.	Near Cuttack (Orissa)	2.045	2.368	142.3
SST.	Nahan (Himachal P.)	2.250	2.415	149.2
SST.	Dholpur Area (Raj)	2.291	2.651	163.9
SST.	Kotah Area (Raj.)	2.669)	2.723	171.4
SST.	Jodhpur Area (Raj)	2.451	2.691	159.8
SST.	Bhilwara Area (Raj)	2.491	2.702	170.7
SST.	Bikaner Area (Raj.)	2.675	2.718	169.9
SST.	Mirzapur Area (U.P)	2.483	2.653	163.5
SST.	Fatehpur Sikri Area (U.P)	2.528	2.602	159.2

Table No.15.

Sample Index Number	Macro-Porosity Percent	Micro-Porosity Percent	Total Porosity Percent	Pore Structure
1 SST.	1.81	.31	2.12	Open outside and closed outside.
2 SST.	11.26	3.86	15.12	Closed pores.
3 SST.	1.11	1.51	2.62	Open pores allowed easy passage fatigues.
4 SST.	15.28	2.71	17.99	Not determined.
5 SST.	18.72	3.89	22.61	Open pores allow free entry exit to solutions.
6 SST.	n.d.	n.d.	8.33	Not determined
7 SST.	n.d.	n.d.	3.07	-do-
8 SST.	3.95	2.1	6.05	Open as well as closed type.
9 SST.	3.28	3.21	6.49	Open pores allow free passage for solutions.
0 SST.	n.d.	n.d.	4.83	-do-
1 SST.	8.51	4.07	12.58	-do-
2 SST.	3.82	1.38	5.20	Not determined
3 SST.	3.53	2.21	5.74	Open as well as closed pores
4 SST.	10.55	3.16	13.21	Not determined.
5 SST.	n.d	n.d	6.83	Open as well as closed pores
6 SST.	8.05	5.52	13.57	Open outside and closed inside.
7 SST.	1.12	0.76	1.98	-do-
8 SST.	6.23	2.74	8.97	-do-
9 SST.	n.d.	n.d.	7.82	Not determined
0 SST.	n.d.	n.d.	1.58	Not determined
1 SST.	3.62	2.79	6.41	Open outside and closed inside
2 SST.	n.d.	n.d.	2.84	-do-

Macro pores = Pores larger than 0.005 mm.
Micro pores = Pores smaller than 0.005 mm.

Table No. 16.

(C) WATER ABSORPTION AND SATURATION COEFFICIENT

Sample Index Number	Water Absorption Percent by Weight: 24 hours (Cold)	Water Absorption Percent by Weight: 5 hours (Boiling)	Coefficient by weight
1 SST.	2.15	2.94	.73
2 SST.	4.01	8.54	.58
3 SST.	2.19	2.33	.94
4 SST.	7.18	10.90	.66
5 SST.	3.92	5.33	.58
6 SST.	2.89	4.61	.63
7 SST.	2.47	2.79	.89
8 SST.	3.01	3.81	.80
9 SST.	3.92	5.33	.58
10 SST.	4.86	8.21	.59
11 SST.	6.07	10.98	.55
12 SST.	0.42	0.62	.68
13 SST.	2.25	2.66	.85
14 SST.	2.32	4.01	.58
15 SST.	3.12	3.50	.89
16 SST.	4.33	5.39	.80
17 SST.	1.05	1.35	.77
18 SST.	2.26	3.00	.75
19 SST.	1.50	1.63	.92
20 SST.	2.86	3.45	.82
21 SST.	1.17	3.31	.35
22 SST.	2.23	3.58	.63

Table No. 17.

CHEMICAL COMPOSITION

Sample Index Number	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O K_2O	Loss on ignition
1 SST.	98.69	tr.	1.06	0.42	0.01	0.17	----
5 SST.	78.24	3.82	10.88	0.95	1.60	1.73	----
7 SST.	88.45	3.03	3.92	0.36	0.12	0.88	----
9 SST.	82.05	2.71	5.27	3.35	0.75	0.80	4.40
14 SST.	93.13	2.34	1.19	0.32	0.12	----	0.39
16 SST.	97.10	----	2.20	0.60	0.10	----	----
21 SST.	96.82	0.67	0.51	0.04	0.001	----	----
17 SST.	99.02	0.29	0.51	----	----	0.18	----

Table No. 18.

LATERITE

Physical Properties

A. Specific Gravity and Wt/Cu.ft. in lbs.

Sample Index Number	Locality	Apparant Specific Gravity	True Specific Gravity.	Wt./Cu.ft. in lbs.
1 LT.	Pattukkottai (Madras)	1.283	2.396	80.76
2 LT.	Bhandara (Maha)	1.197	2.598	76.89
3 LT.	Belgaum (Mys.)	1.408	3.064	95.37
4 LT.	Coastal Distt. (Orissa)	1.335	2.872	69.95

Table No. 19.

B. Porosity Characteristics

Sample Index Number	Macro-porosity percent	Micro-porosity Percent.	Total Porosity Percent	Pore-structure
1 LT.	40.35	6.1	46.45	Most of the pores are continuous. Pores are mostly of very big size. It permits flow of solutions but not so easily as its porosity.
2 LT.	50.83	3.9	53.92	
3 LT.	52.79	1.25	54.04	
4 LT.	49.37	4.14	53.51	

Table No.20.

Not Clear

C. Water Absorption and Saturation Coefficient

Sample Index Number	Water Absorption Percent by weight		Saturation coefficient by weight
	24 hours cold	5 hours boiling	
1 LT.	14.36	16.78	.85
2 LT.	18.87	21.05	.89
3 LT.	21.63	22.07	.98
4 LT.	16.59	18.35	.90

Table No. 21

D. Chemical Analysis

Sample Index Number	SiO_2%	Fe_2O_3%	Al_2O_3%	CaO%	MgO%	TiO_2%	Loss on Ig.%
1 LT.	40.17	15.02	25.14	.23	0.1	0.15	10.13
2 LT.	2.32	56.63	7.89	0.45	0.84	6.04	19.28
3 LT.	3.02	78.97	4.93	0.16	0.06	0.10	6.0
4 LT.	1.37	67.64	4.27	0.42	0.04	01.04	20.30

Table No. 22.

LIME STONES

Physical Properties

A. Specific Gravity and Wt/Cu.ft. in lbs.

Sample Index Number	Locality	Apparent Specific gravity	True specific gravity.	Wt./Cu.ft. in lbs.
1 LMST.	Khasi Hills (Assam)	2.003	2.108	140.1
2 LMST.	Kurnool, Cuddapah Anantpur, Guntor (The Cuddapah Slabs)	2.804	2.823	171.8
3 LMST.	Tandur (Shahbad Slabs)	2.731	2.762	169.2
4 LMST.	Pindara (Gujerat)	2.537	2.704	135.7
5 LMST.	Katni (M.P)	2.023	2.105	144.76
6 LMST.	Khandara (M.P)	2.167	2.192	146.83
7 LMST.	Kaladgi (Mysore)	2.649	2.683	168.8
8 LMST.	Simla (Punjab)	2.330	2.374	158.6
9 LMST.	Ramganjmandi (Raj.) (Kotah Stone)	2.720	2.750	170.2
10 LMST.	Chittor (Raj.)	2.568	2.601	167.3
11.LMST.	Jaisalmer (Raj.)	2.095	2.305	119.7

Table No. 23.

B. POROSITY CHARACTERISTICS

Sample Index Number	Macro-porosity Percent.	Micro-porosity Percent	Total porosity percent	Pore Structure
1 LMST.	n.d.	n.d.	4.98	Not determined
2 LMST.	.61	.06	.67	Isolated
3 LMST.	1.03	.09	1.12	-do-
4 LMST.	4.97	1.61	6.58	Open and isolated
5 LMST.	2.86	.89	3.75	-do-
6 LMST.	n.d.	n.d.	1.17	Not determined
7 LMST.	n.d.	n.d.	1.19	-do-
8 LMST.	1.05	.85	1.85	Open
9 LMST.	1.02	.07	1.09	Open and isolated
10 LMST.	n.d.	n.d.	1.26	Not determined
11 LMST.	5.33	3.78	9.11	Open and a few isolated

Table No. 24.

C. WATER ABSORPTION AND SATURATION - COEFFICIENT

Sample Index Number	Water Absorption Percent by Weight		Saturation Co-efficient
	24 hours cold	5 hours Boiling	
1 LMST.	1.02	1.12	.91
2 LMST.	0.09	0.13	.69
3 LMST.	0.26	0.29	.89
4 LMST.	.87	.96	.90
5 LMST.	1.08	1.35	.80
6 LMST.	1.36	1.52	.89
7 LMST.	0.20	0.23	.86
8 LMST.	1.02	1.22	.83
9 LMST.	0.15	0.17	.88
10 LMST.	0.82	0.90	.91
11 LMST.	1.25	1.75	.71

Table No. 25.

D. CHEMICAL COMPOSITION

Sample Index Number	SiO_2	Al_2O_3	Fe_2O	CaO	MgO	$Na_2O + K_2O$	Loss on Ig.
1 LMST.	2.93	0.54	n.d.	54.22	0.22	n.d.	42.58
2 LMST.	15.06	5.82	0.68	43.75	n.d.	n.d.	34.02
3 LMST.	18.03	4.08	0.53	44.12	0.75	n.d.	35.12
5 LMST.	3.66	1.01	0.28	52.29	0.97	n.d.	41.72
7 LMST.	14.09	1.83	0.77	40.60	4.49	1.2	35.58
9 LMST.	19.16	4.92	0.76	41.05	0.86	n.d.	33.24
11 LMST	24.32	3.85	10.97	32.13	3.87	n.d.	26.08

Table No. 26.

GRANITE

Physical Properties

A. Specific Gravity and Wt/Cu.ft. in lbs.

Sample Index Number	Locality	Apparant specific gravity.	True Specific Gravity.	Wt/Cuft. in lbs.
1 GR.	Hyd. West Taluka (And)	2.753	2.771	177.8
2 GR.	Guntur (And.)	2.684	2.702	175.3
3 GR.	Bhulvan (Guj.)	2.701	2.723	168.5
4 GR.	Coastal Tract of Madura	2.501	2.620	170.8
5 GR.	Bangalore	2.721	2.789	179.1
6 GR.	Sambalpur	2.691	2.706	173.4

Table No. 27.

B. Porosity Characteristics

Sample Index Number	Macro-porosity percent	Micro-porosity percent.	Total porosity percent	Pore-structure
1 GR.	.43	.21	.64	closed
2 GR.	.52	.14	.66	-do-
3 GR.	.57	.23	.80	-do-
4 GR.	.47	.25	.72	-do-
5 GR.	.32	.08	.40	-do-
6 GR.	.43	.12	.56	A few open pores but mostly closed

Table No.28.

C. Water Absorption and Saturation Coefficient

Sample Index Number	Water Absorption percent by weight		Saturation coefficient
	24 hours cold	5 hours boiling	
1 GR.	.09	.10	.90
2 GR.	.07	.08	.87
3 GR.	.12	.14	.85
4 GR.	.08	.09	.88
5 GR.	.07	.08	.87
6 GR.	.15	.16	.93

Table No.29.

D. CHEMICAL COMPOSITION

Sample Index Number	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Soda	Potash	Loss on Ig.
1 GR.	76.54	13.82	1.62	-	0.85	0.01	4.32	2.31	0.20
2 GR.	73.65	11.19	1.31	3.25	2.78	0.51	3.74	1.86	0.44
3 GR.	68.24	16.30	1.37	2.13	3.20	1.88	4.20	2.10	0.24
4 GR.	72.35	13.78	1.87	0.36	0.87	0.42	4.49	4.44	0.76
5 GR.	77.05	11.77	2.33	n.d.	2.21	n.d.	3.88	2.90	0.52
6 GR.	71.88	12.88	3.05	1.05	1.13	0.33	4.46	4.21	0.43

Table No. 30

MISC. IGNEOUS ROCKS

Physical Properties

Specific Gravity and Wt/Cu.ft. in lbs.

Sample Index Number	Name of Rock	Locality	Apparent Specific Gravity	True specific Gravity	Wt/Cu.ft. in lbs.
1 BS.	Basalt	Amreli (Guj.)	2.792	2.801	182.4
2 BS.	Basalt (Trap)	Nagpur (Maha)	2.968	2.980	185.3
1 DL.	Dolerite	Dodballabpur (Mys)	2.861	2.870	178.2
1 AT.	Acidic Traps	Baroda (Gujerat)	2.536	2.587	168.5
1 TT.	Trachytic Trap	Bardaria Hill (Guj.)	2.488	2.523	165.7
2 TT.	Trachytic Trap	Bombay (Kuria Trap) (Kangatta Hill)	2.605	2.634	170.5
1 DI.	Diorite	Mandya Distt.	2.727	2.753	173.1
2 DI.	Diorite	Sriranga-Patna (Mys)	2.790	2.813	174.5
1 NO.	Norite	Nagowala (Mys)	2.805	2.815	179.8
1 GB.	Gabbro	Maddur (Mys)	2.796	2.808	180.7
1 SY.	Syenite	Kodiyala (Mandya)	2.528	2.562	163.2
2 GP.	Granite Perphry	(Charumudi Hill) Mys.	2.679	2.780	170.8
1 CH.	Charnockite	Kodavidu Hill (Andhra)	2.803	2.812	180.2

Table No.31

B. POROSITY CHARACTERISTICS

Sample Index Number	Macro-porosity	Micro-porosity	Total porosity	Pore-Structures
1 BS.	.11	.21	.32	Closed & Isolated
2 BS.	n.d.	n.d.	.40	Not determined
1 DL.	.12	.19	.31	Closed and Isolated
1 AT.	1.12	.85	1.97	Closed but a few open
1 TT.	.85	.53	1.38	-do-
2 TT.	n.d.	n.d.	1.11	Not determined.
1 DI.	.45	.49	.94	Closed and Isolated
2 DI.	n.d.	n.d.	.81	Not determined
1 NO.	.12	.23	.35	Closed and Isolated
1 GB.	.31	.11	.42	-do-
1 SY.	.45	.87	1.32	-do-
2 GP.	1.74	1.89	3.63	Closed and open
1 CH.	.1	.22	.32	Closed and Isolated

Table No. 32.

C. WATER ABSORPTION AND SATURATION COEFFICIENT

Sample Index Number	Water Absorption Percent		Saturation coefficient
	24 hrs. cold	5 hrs. boiling	
1 BS.	.08	.09	.87
2 BS.	.07	.07	1.0
1 DL.	.06	.07	.85
1 AT.	.14	.16	.87
1 TT.	.12	.15	.80
2 TT.	.89	.97	.81
1 DI.	.09	.10	.90
2 DI	.08	.09	.88
1 NO.	.01	.08	.87
1 GB.	.08	.08	1.0
1 SY.	.13	.15	.86
2 GP.	1.05	1.15	.91
1 CH.	.06	.07	.85

Table No.33

D. CHEMICAL ANALYSIS

Sample Index Number	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss on igneous
1 BS.	42.30	14.24	3.96	5.40	15.42	5.20	2.40	0.27	2.24
*2 BS.	51.09	14.23	2.56	7.14	10.35	7.56	1.92	0.42	2.67
1 DL.	49.21	14.04	3.61	7.69	10.08	7.11	2.71	0.78	2.59
1 AT.	n.d.	n.d.	n.d	n.d	n.d.	n.d.	n.d.	n.d.	n.d.
1 TT.	60.12	16.26	1.67	3.76	4.47	2.52	4.17	1.19	3.05
2 TT.	n.d.	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1 DI.	56.30	14.01	0.71	5.79	6.73	10.10	3.13	2.09	3.38
2 DI.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1 GB.	45.80	16.34	1.67	12.53	8.44	5.39	3.11	0.75	2.43
1 SY.	51.23	18.96	3.12	3.89	1.88	3.61	3.04	7.79	4.07
2 GP.	72.10	12.04	4.63	0.29	1.11	0.27	3.20	5.31	1.12

*TiO_2 = 1.03

Table No.34

MARBLES AND CRYSTALLINE LIMESTONES

Physical Properties

A. Specific Gravity and Wt/Cuft. in Lbs.

Sample Index Number	Locality	Apparant Specific Gravity	True specific Gravity	Wt/Cu.ft. in lbs.
1 CL.	Yellandu in Warrangal Distt. (Andhra)	2.653	2.668	179.7
2 CL.	Bettadabidu (Mys)	2.690	2.701	167.8
1 MB.	Motipur (Gujerat)	2.679	2.710	n.d.
2 MB.	Makrana (Raj.)	2.860	2.884	178.2
3 MB.	Devimata (Raj.)	2.734	2.750	175.0
4 MB.	Narnaul (Punjab)	2.725	2.742	177.6

Table No.35

B. Porosity Characteristics

Sample Index Number	Macro-porosity percent	Micro-porosity percent	Total porosity percent	Pore-structure
1 CL.	.13	.43	.56	Closed
2 CL.	.08	.32	.40	-do-
1 MB.	.51	.56	1.07	-do-
2 MB.	.22	.61	.83	-do-
3 MB.	n.d.	n.d.	.58	n.d.
4 MB.	.21	.41	.62	closed

Table No. 36

C. Water Absorption & Saturation Coefficient

Sample Index Number	Water Absorption Percent		Saturation coefficient
	24 hrs. cold	5 hrs. boiling	
1 CL.	.08	.09	.87
2 CL.	n.d.	n.d.	n.d.
1 MB.	.35	.45	.87
2 MB.	.09	.10	.90
3 MB.	.11	.13	.84
4 MB.	.08	.09	.87

Table No. 37.

D. CHEMICAL COMPOSITION

Sample Index Number	SiO_2	Fe_2O_3	DrO_3	CaO	MgO	Nar K_2O	Loss on Igneous
1 CL.	1.89			43.60	10.05		44.63
2 CL.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1 MB.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2 MB.	0.82			54.81	2.7		43.56
3 MB.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4 MB.	1.10	0.19		53.96	1.60		43.27

Table No. 38.

SLATES

Physical Properties

A. Specific Gravity in Wt/Cu.ft.

Sample Index Number	Locality	Apparent Specific Gravity.	True Specific Gravity.	Wt/Cu.ft. in lbs.
1 SL.	Coinburn (Kurnool Distt.) Andhra.	2.784	2.796	171.3
2 SL.	Yemaguntla (Cuddapah)	(See under limestones 2 Lm)		
3 SL.	Kharakpur Hill (Bihar)	2.675	2.702	n.d.
4 SL.	Surajpur (Gujarat)	2.755	2.795	170.5
5 SL.	Dharamshala (H.P)	2.706	2.756	168.3
6 SL.	Kund (Punjab)	2.7[illegible]	2.782	171.

Table No. 39.

B. Porosity Characteristics

Sample Index Number	Macro-porosity Percent	Micro-porosity percent	Total porosity percent	Pore-structure
1 SL.	.24	.18	.42	Lenticular pores but closed at both ends.
2 SL.	(See under Limestone's 2 Lm.St)			
3 SL.	.37	.62	.99	-do-
4 SL.	.58	.85	1.43	-do-
5 SL.	1.02	.79	1.81	-do-
6 SL.	.23	.52	.75	-do-

Table No.40.

C. Water Absorption and Saturation Co-efficient

Sample Index Number	Water Absorption Percent		Saturation coefficient
	24 hrs. cold	5 Hrs. Boiling	
1 SL.	.07	.08	.87
2 SL.	(See under Limestones 2 Lm.St)		
3 SL.	.12	.16	.75
4 SL.	.39	.46	.84
5 SL.	.52	.61	.85
6 SL.	.09	.10	.90

Table No. 41.

D. CHEMICAL COM POSITION

Sample Index Number	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss on Ignition
1 SL.	55.58	24.53	0.11	8.70	0.42	1.95	1.71	3.17	5.38
2 SL.	(See under Limestone 2 Lm.St)								
3 SL.	69.04	12.66	6.55	1.30	1.75	1.87	0.09	2.98	4.84
4 SL.	54.76	24.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
5 SL.	56.33	22.26	5.21	4.23	0.68	1.48	1.49	3.58	4.96
6 SL.	58.30	21.89	7.05	2.57	0.39	1.09	1.18	2.45	4.61

Table No. 42.

MISC. METAMORPHIC ROCKS

Physical Properties

Specific Gravity and Wt/Cu.ft. in lbs.

Sample Index Number	Name of Rock	Locality	Apparant Specific Gravity	True specific gravity	Wt/Cu.ft. in lbs
1 QZT.	Quartzite	Alwar (Raj)	2.732	2.748	173.5
2 QZT.	Quartzite	Kishangarh (Raj.)	2.756	2.764	168.4
3 QZT.	Quartzite	Jhirit (Alwar Dist)	2.695	2.705	171.7
4 QZT.	Quartzite	Delhi	2.738	2.752	169.9
1 GN.	Gneiss	Darjeeling	2.653	2.676	165.8
2 GN.	Garnetiferous Gneiss.	Sambalpur	2.496	2.587	162.6
1 PH.	Phyllites.	Jainbughoda (Guj)	2.543	2.678	170.1
2 PH.	Phyllites	Balaghat (M.P)	2.478	2.597	161.9
3 PH.	Phyllites	Goda (Raj.)	2.605	2.775	170.5
1 SCH.	Horn. Chloritic Hematitic schist.	Dharwar	2.837	2.885	181.2
1 KH.	Khandalite	Paidipadu (Andhra)	2.758	2.803	179.7

Table No.43.

B. POROSITY CHARACTERISTICS.

Sample Index Number	Macro-porosity percent	Micro-porosity percent	Total porosity percent	Pore Structure
1 QZT.	.16	.42	0.58	Closed but seldom opened.
2 QZT.	.12	.17	0.29	-do-
3 QZT.	n.d.	n.d.	0.37	Not determined.
4 QZT.	n.d.	n.d.	0.15	Not determined
1 GN.	.27	.59	.86	Closed and open also
2 GN.	n.d.	n.d.	.81	Not determined
1 PH.	1.77	3.27	5.04	Closed and open also
2 PH.	1.63	2.95	4.58	-do-
3 PH.	n.d.	n.d.	6.12	Not determined.
1 SCH.	.64	1.05	1.61	Closed and open mostly open
1 KH.	1.01	.59	1.6	Closed and open

Table 44.

C. WATER ABSORPTION AND SATURATION COEFFICIENT

Sample Index Number	Water Absorption Percent by Weight		Saturation coefficient
	26 hrs. cold	5 hrs. boiling	
1 QZT.	.09	.10	.90
2 QZT.	.07	.07	1.00
3 QZT.	.06	.07	.85
4 QZT.	.08	.09	.87
1 GN.	1.51	1.63	.92
2 GN.	1.21	1.42	.85
1 PH.	3.05	4.15	.73
2 PH.	2.89	3.25	.88
3 PH.	4.15	5.25	.79
1 SCH.	2.73	3.01	.90
1 KH.	4.26	5.65	.75

(Table 45)

CHEMICAL COMPOSITION

Sample Index Number.	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	Loss on Ig.
1 QZT.	99.27	0.10	0.26					.....
2 GN.	64.46	6.36	14.60	3.50	2.78	2.62	3.31	.....
1 PH.	60.15	6.94	16.45	1.41	2.32	1.01	3.60	.....
1 SCH.	59.97	6.91	21.25	0.49	2.12	1.39	2.92	.....
1 KH.	74.5	6.82	18.16	0.61	0.83	0.49		
						(Na_2O) Trace		0.11

Table No.46.

DISCUSSION OF RESULTS

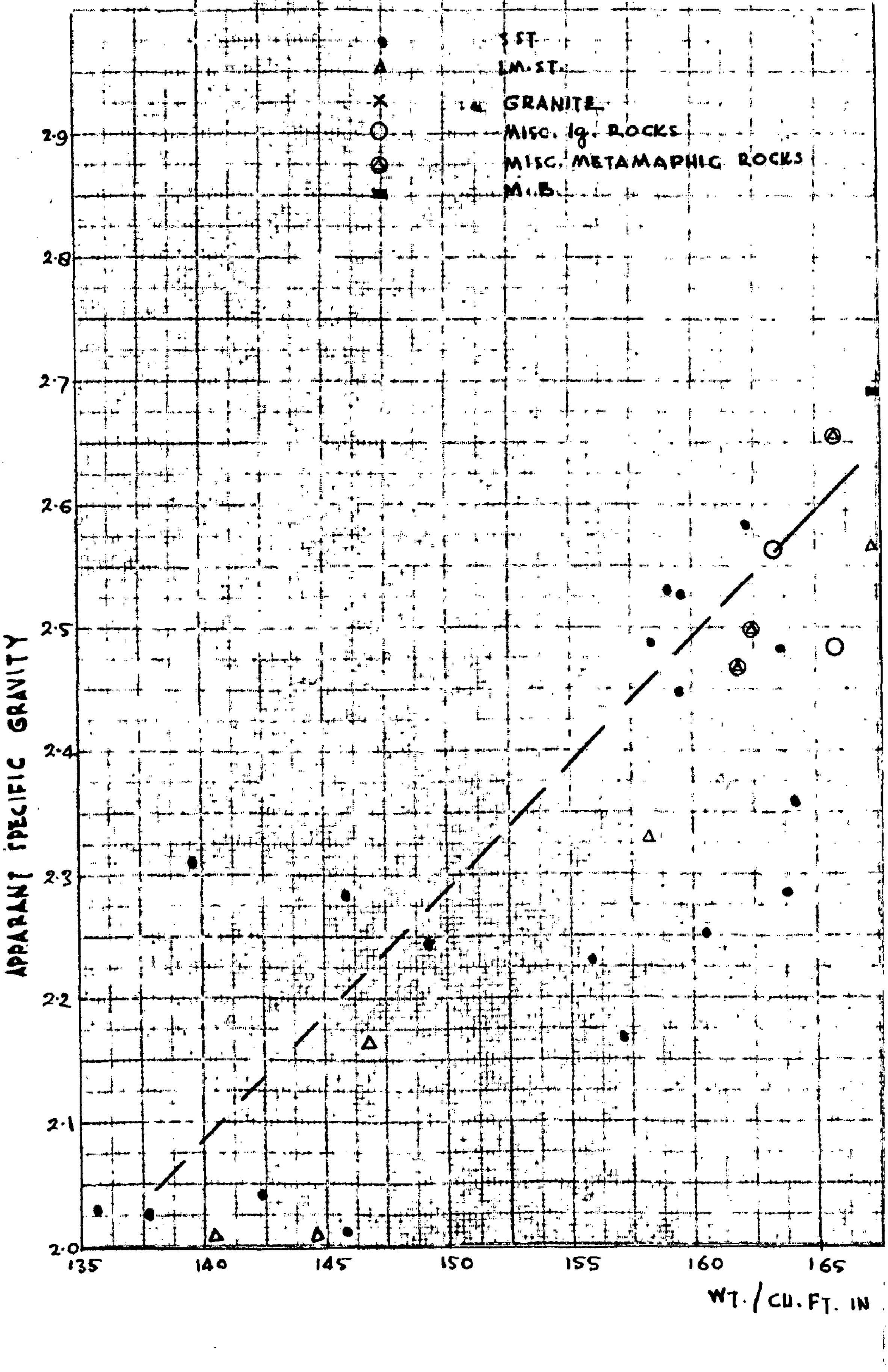
Specific Gravity and Wt./Cu./ft. :-

Specific gravity of stones is a valuable property. In accordance with the fundamental principles of our knowledge the greater the specific gravity the greater is its strength.

The relationship between apparant specific gravity and the true specific gravity against weight per cubic foot has been shown in Figs 15 & 16. From the study of these curves it is clear that apparant specific gravity is more directly connected to the weight per cubic foot than the true specific gravity and this is explained on the basis of the available pore spaces within the sample. The pore space appear to play an important role and this is fully accounted for in the determination of apparant specific gravity, whereas there is no representation of these spaces in case of true specific gravity. As explained in the chapter on experimental techniques, we find that for the determination of apparant specific gravity a test price is cut of the rock as it is and, therefore, all the voids, air spaces, pores, channels that were present in the rock are fully or partially represented in the test specimens. However, the case is just the opposite in the case of true specific gravity. Here the rock is reduced to powder and the question of pore and air spaces representation does not arise. Hence, apparant specific gravity gives a better idea of the nature of stone than the true specific gravity.

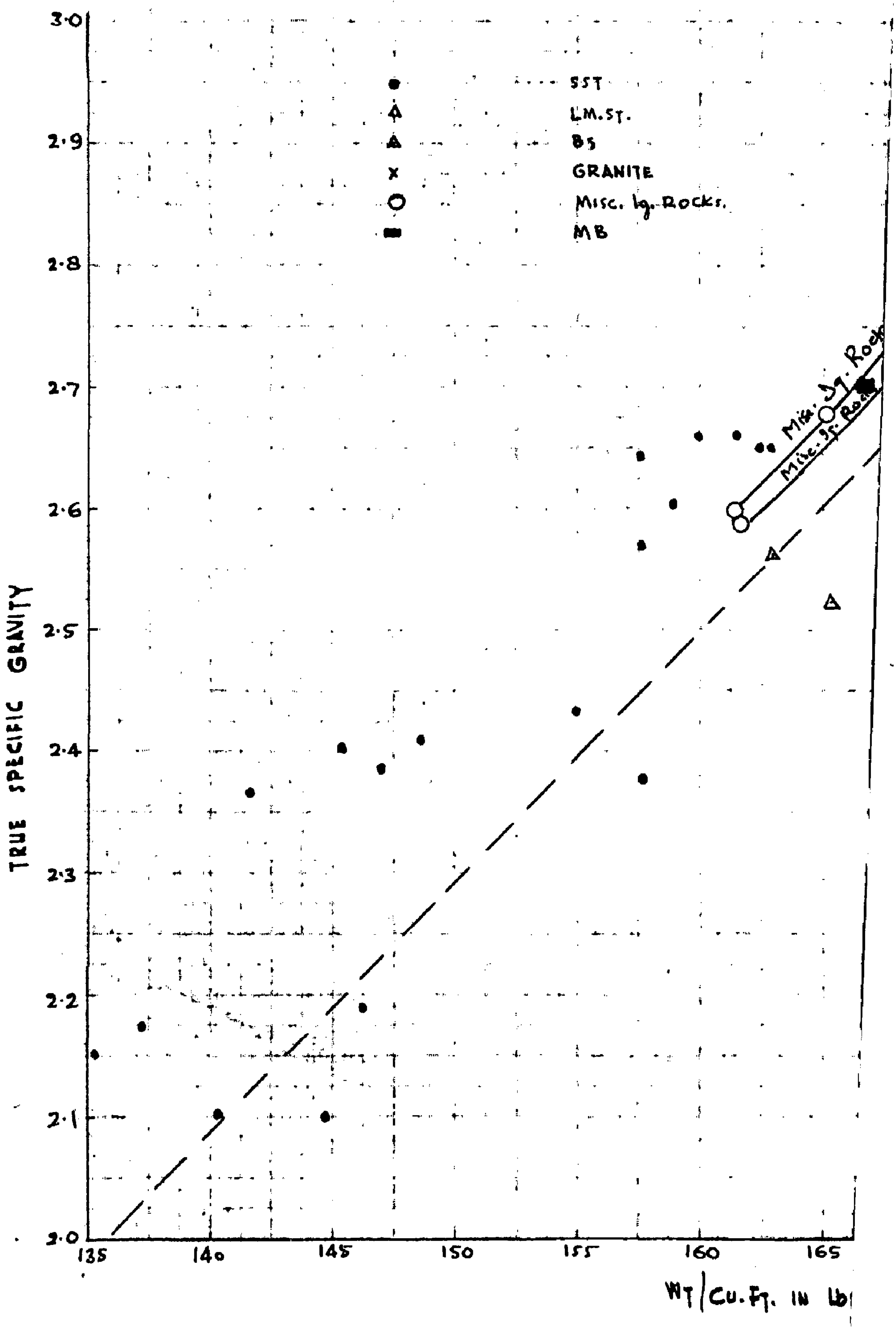
APPARANT SPECIFIC GRAVITY Vs. WT./CU.

FIG. 15



TRUE SPECIFIC GRAVITY Vs. WT./CU. FT.

FIG. No. 16



Absorption and Saturation Coefficient

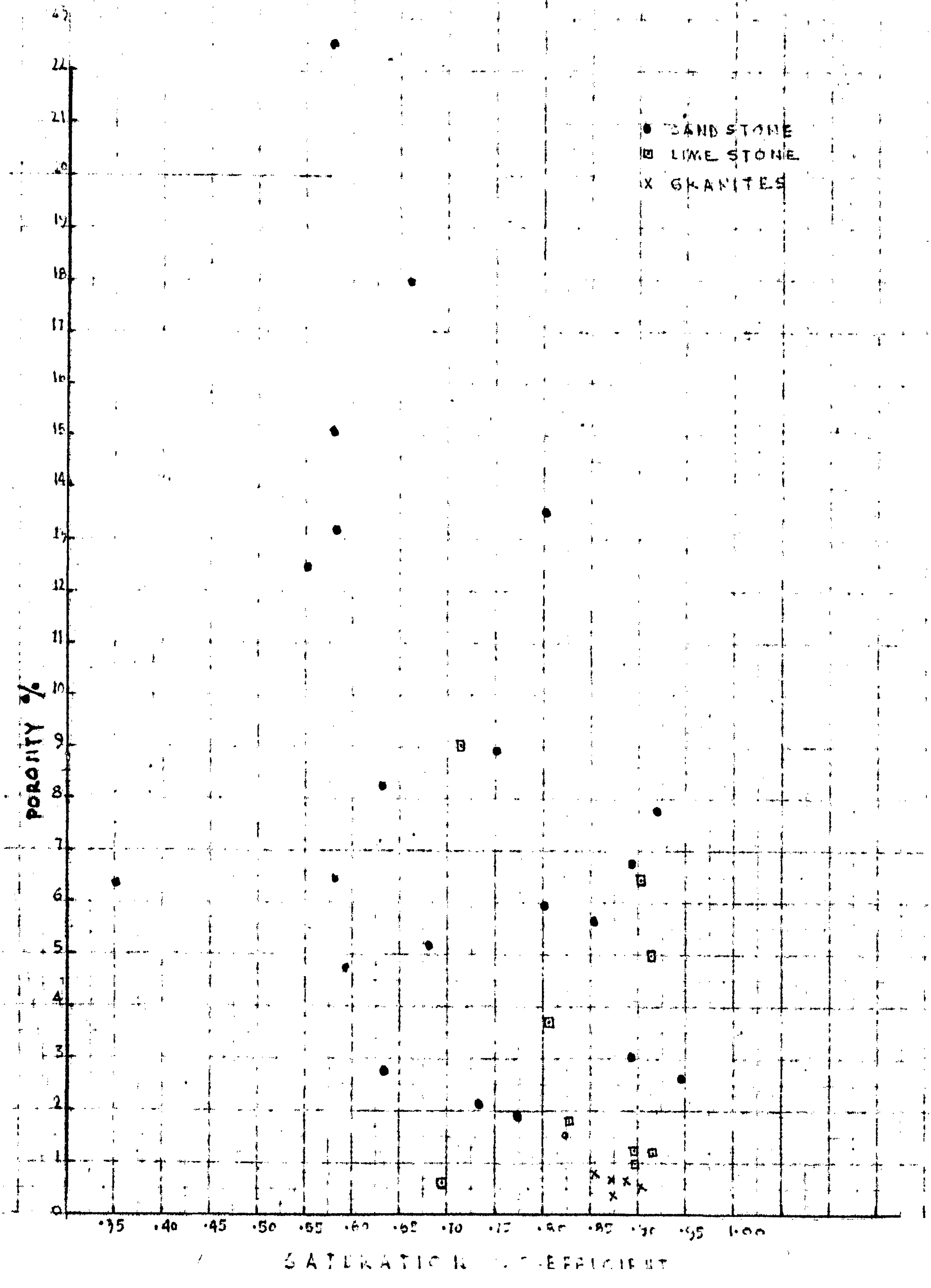
Absorption capacity as indicated by Shaffer [42] is the amount of water absorb in 24 hours time. This is directly related to the shape and size of grains and texture etc. of the rocks. Simple immersion in water does not lead to complete saturation as the water fails to reach all the available pores. This is because of the pores which are completely cut off, there is no access of water in that part of the rock and the entrapped air spaces do not get replaced by the water.

Though Hirschwald's [43] was much occupied with the effect of frost on stones, but it was he, who conrieved the idea of saturation coefficient as a measure of durability in the stones. The saturation coefficient is a measure to the extent to which the pores get filled up when the sample is allowed to absorb water for a limited time and under particular conditions of temperature and other experimental factors.

In order to study the relationship and the behaviour of inherent characteristics, porosity, microporosity and macroporosity as defined by Scott Russell[44] have been determined and plotted in a graph against 'Saturation - Coefficient' in Figs. 17, 18 & 19. As is evident from these figures all the three porosity characteristics show no bearing on the saturation coefficient. However, it is certain that the extent to which the displacement of air by water occurs is not fortutous. The saturation coefficient measured under constant conditions is a characteristic property of the material and depends upon the configuration of the pores. This is because of the fact that absorption is usually incomplete and the saturation coefficient

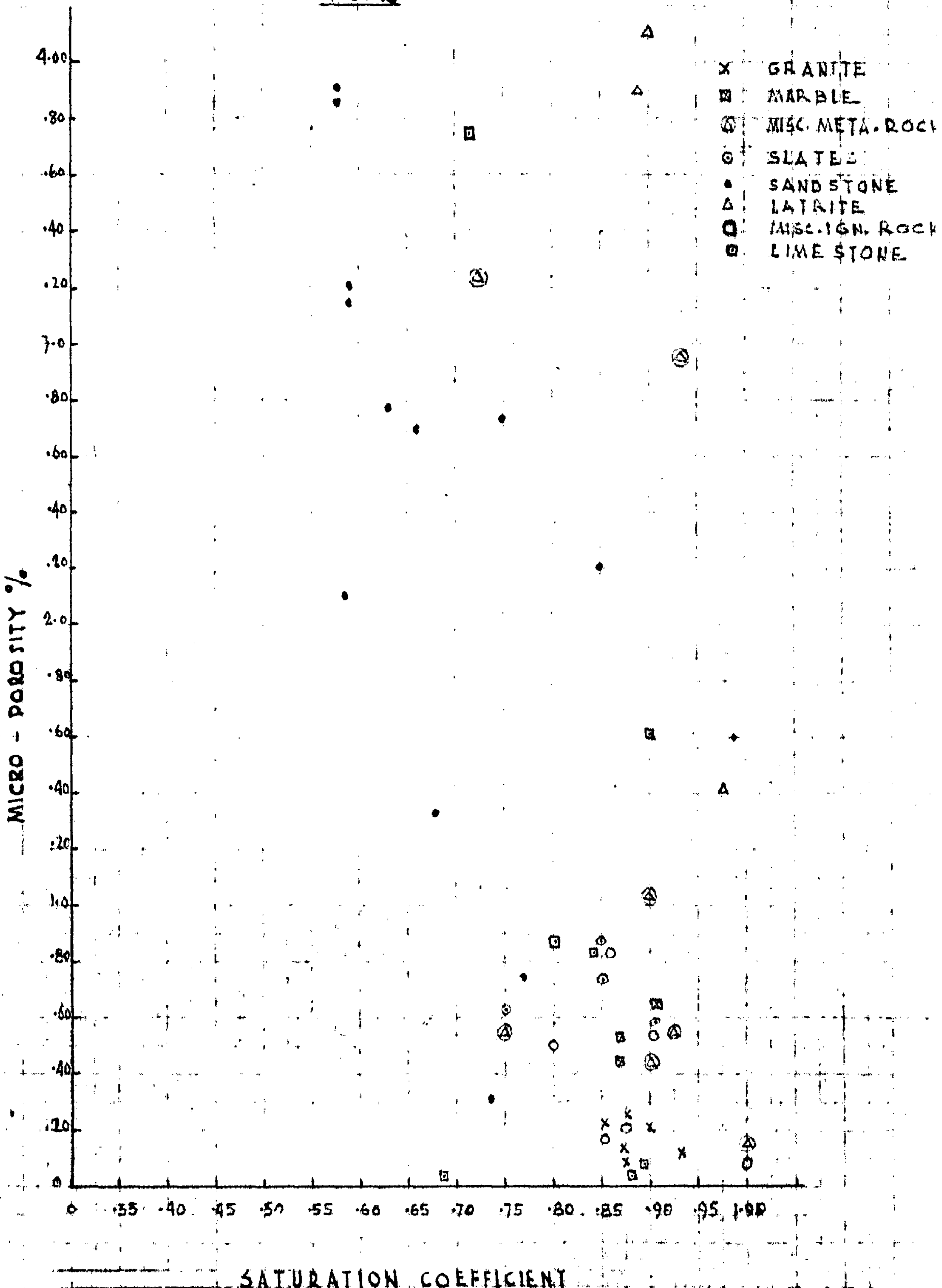
POROSITY Vs. SATURATION COEFFICIENT

FIG. 17



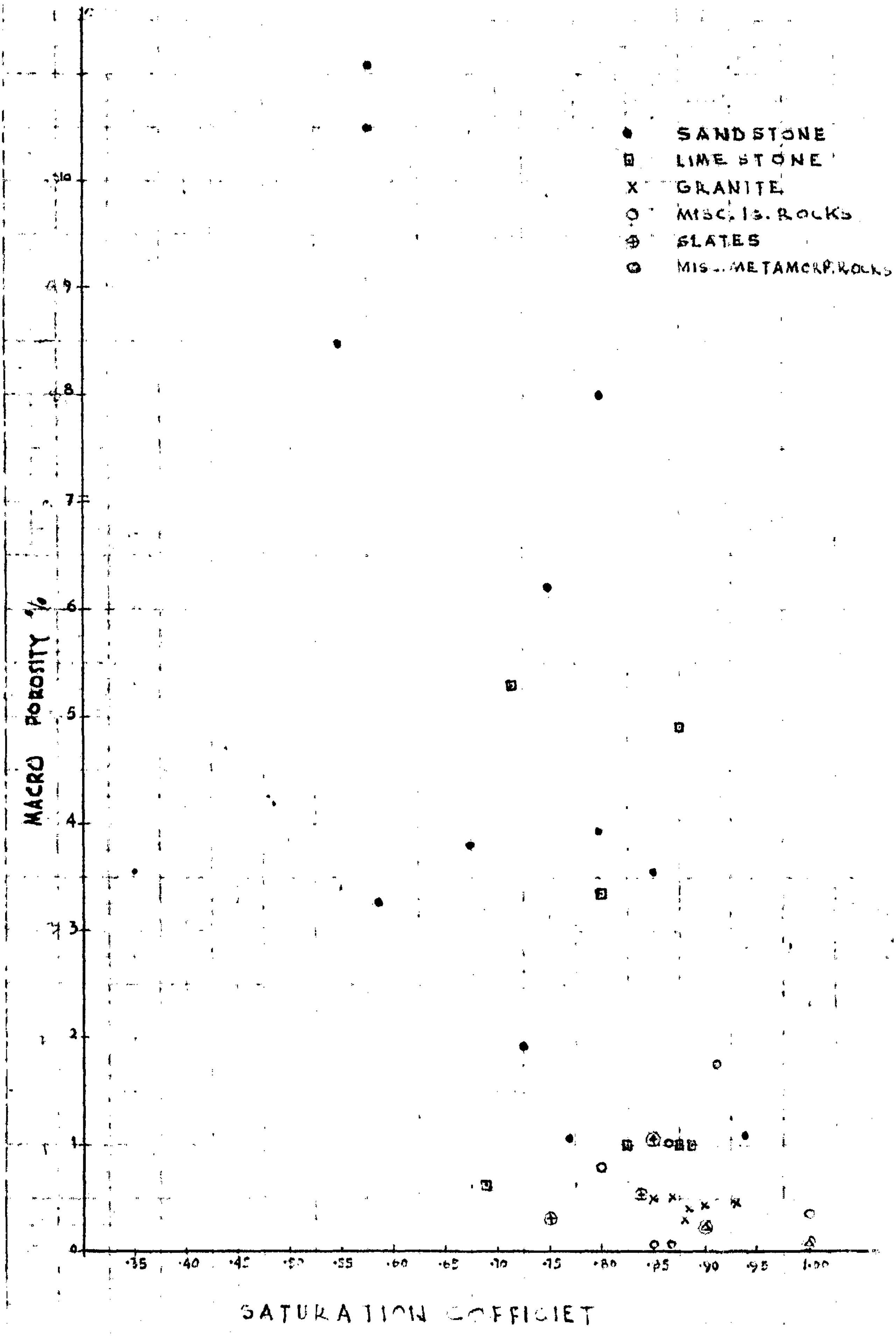
MICRO POROSITY Vs. SATURATION COEFFICIENT

FIG. 18.



MACRO POROSITY Vs. SATURATION COEFFICIENT

FIG. 19



affords a somewhat crude measure of the pore-structure.

This shows that an attempt to quantitatively evaluate the pore-structure is definitely an advance towards physical evaluation of the property of a building stone, from the point of view of durability as it is related to the pore-structure more than other porosity characteristics. An indirect attempt in this direction has been made by Honey Borne and Harris[45] in which they have based their observations on the relationship between the water content and the difference in pressure that exists across the curved air/water interface in the partially saturated material.

Chemical Analysis :

Although the interpretation of the chemical analysis is imperfect and unsatisfactory, still it has not been thought advisable to neglect this important aspect in these pages.

With suitable interpretations the chemical data given here can also be an index of the weathering behaviour of building stones. Moreover, the phenomena of efflorescence in the building stones and its relationship with the chemical composition of stones under the variable conditions of weathering especially so under tropical climates, is of special significance. It can be seen that almost all the rocks ranging from sand-stones to granites and slates etc. have magnesium and calcium salts in their composition. The presence of these salts and their accumulation at the surface is the main cause of efflorescene.

Evaluation of mineralogical composition along with the chemical analysis of rocks is essential from the point of view of the reactivity of aggregates and other controlled conditions of construction of huge structures like Bhakra Dam in India and other similar structures in other countries as well.

Conclusions :

The following conclusions are drawn on the basis of the above results and discussions.

(1) The average physical values of Indian Building Stones, range widely as shown in Table No.47.

(2) The relationship obtained between Apparant Specific Gravity and Wt/Cu.ft. as given in Fig.15 shows that both are approximately directly proportional to each other.

(3) The relationship of true specific gravity with Wt/Cu.ft. is less than that which exists between apparant specific gravity and Wt./Cu.ft.

(4) Saturation coefficient as calculated from absorption percentage is not related to microporosity, macroporosity or the total porosity.

(5) Saturation coefficient is a crude measure of pore structure and more efficient quantitative estimation is required to be established.

(6) Physical properties and chemical properties have no relationship and the one does not explain the other in any way.

(7) The presence of calcium and magnesium salts in the chemical

TABLE SHOWING AVERAGE PHYSICAL VALUES OF INDIAN BUILDING STONES RANGE

Nature of Rock	Apparant Specific percent.	True specific gravity %	Wt/Cu.ft. in lbs.	Micro-porosity	Macro-porosity	Total porosity	Saturation coefficient
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sandstones	2.029 to 2.675	2.157 to 2.731	135.6 to 171.4	.31 to 5.52	1.11 to 18.72	1.58 to 22.61	.35 to .94
Laterite	1.197 to 1.408	2.396 to 2.872	69.95 to 95.37	1.25 to 6.1	40.35 to 52.79	46.45 to 54.04	.85 to .98
Limestones	2.003 to 2.804	2.105 to 2.823	119.7 to 171.8	.06 to 3.78	.61 to .5.33	.67 to 9.11	.69 to .91
Granites.	2.501 to 2.753	2.620 to 2.789	168.5 to 179.1	.08 to .25	.32 to .57	.40 to .80	.85 to .93
Basalts.	2.792 to 2.968	2.801 to 2.980	182.4 to 185.3	.21	.11	.32	
Misc. S. Ig. Rocks. as given in Table No.	2.528 to 2.861	2.523 to 2.870	163.2 to 180.7	.11 to 1.89	.1 to 1.74	.31 to 3.63	.85 to 1.0
Marbles	2.653 to 2.860	2.668 to 2.884	167.8 to 179.7	.32 to .56	.08 to .22	.40 to 1.07	.84 to .90
Slates.	2.675 to 2.784	2.702 to 2.796	171.3 to 168.3	.18 to .85	.23 to 1.02	.42 to 1.81	.75 to .90

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Quartzites.	2.695 to 2.756	2.705 to 2.764	168.4 to 173.5	.17 to .42	.12 to .16	.15 to .58	.85 to 1.00
Misc. Metamorphic rocks.	2.478 to 2.758	2.597 2.885	161.9 181.2	.59 to 3.27	.27 to 1.77	.81 to 6.12	.73 to .92

Table No.47.

CHAPTER No. VI.

ENGINEERING PROPERTIES AND CLASSIFICATION OF BUILDING STONES IN INDIA

With a view to simplify the use of 'Building Stones' in the engineering profession and the trade in this country an attempt has been made to classify the hardness of rocks in a numerical order. As stated earlier in the preceeding chapter, the engineering properties of rocks used as 'Building Stones' have also not been determined so far. In order to establish certain relationships amongst physico-engineering properties, the compressive strength, the modulus of rupture and the shearing strengths have been determined seperately for two different rift directions. Results given are only for the stones which are quarried at present. Besides the discussions and conclusions together with the proposed classification, it is presumed that the tables will also serve as a source of useful reference of these properties in case of Indian Stones.

SANDSTONES

COMPRESSIVE STRENGTH

Lbs/Sq.in.

Sample Index Number	Average parallel to the Rift Plane	Average perpendicular to rift plane	Average	Average Range
1 SST.	19,022	19,589	19,305	
2 SST.	14,812	15,023	14,917	
3 SST.	15,869	15,939	15,903	
4 SST.	12,210	13,084	12,647	
5 SST.	4,369	4,501	4,535	
6 SST.	9,875	9,946	9,910	
7 SST.	11,947	12,232	12,089	4500
8 SST.	13,662	13,867	13,764	to
9 SST.	4,486	4,693	4,509	19850
10 SST.	14,800	14,300	15,050	
11 SST.	12,911	13,064	12,987	
12 SST.	13,538	13,765	13,651	
13 SST.	11,976	12,288	12,132	
14 SST.	14,768	14,976	7,872	
15 SST.	13,656	13,988	13,822	
16 SST.	18,987	19,536	19,261	
17 SST.	19,432	19,873	19,602	
18 SST.	18,328	18,939	18,683	
19 SST.	18,575	18,885	18,730	
20 SST.	19,687	20,011	19,849	
21 SST.	16,802	17,088	16,945	
22 SST.	17,270	17,835	17,552	

TABLE No. 48

SHEAR STRENGTH
Lbs/Sq.inch

Sample Index Number	Av. parallel to the Rift Plane	Average perpendicular to Rift Plane	Average	Average Range
1 SST.	2002	2020	2011	
2 SST.	1608	1694	1651	
3 SST.	1835	1903	1869	
4 SST.	1004	1102	1053	
5 SST.	568	605	636	
6 SST.	-	-	-	
7 SST.	1125	1138	1131	
8 SST.	1255	1303	1297	
9 SST.	-	-	-	631
10 SST.	1704	1759	1731	to
11 SST.	-	-	-	4404
12 SST.	610	653	631	
13 SST.	1510	1539	1524	
14 SST.	1510	1539	1524	
15 SST.	1703	1747	1725	
16 SST.	2256	2308	2282	
17 SST.	2597	2686	2641	
18 SST.	2709	2803	2756	
19 SST.	2184	2225	4404	
20 SST.	1905	1984	1944	
21 SST.	1242	1302	1270	
22 SST.	1860	1903	1881	

TABLE No. 49.

TRANSVERSE STRENGTH

Modulus of Rupture.

Sample Index Number	Strength value	Direction of Rift plane in relation to direction of bending	Average Range
1 SST.	1990	Parallel	
2 SST.	1505	Parallel	
3 SST.	1778	Parallel	
4 SST.	980	Perpendicular	
5 SST.	504	Perpendicular	
6 SST.	810	Parallel	504
7 SST.	1004	Parallel	to
8 SST.	1217	Perpendicular	2475
9 SST.	n.d	n.d.	
10 SST.	1604	Perpendicular	
11 SST.	1334	Parallel	
12 SST.	1586	Perpendicular	
13 SST.	1208	Parallel	
14 SST.	1437	Perpendicular	
15 SST.	1698	Parallel	
16 SST.	1986	Parallel	
17 SST.	2304	Parallel	
18 SST.	2475	Parallel	
19 SST.	2080	Parallel	
20 SST.	1838	Parallel	
21 SST.	1022	Parallel	
22 SST.	1788	Perpendicular	

TABLE No. 50

LATERITE

Compressive Strength
Lbs/Sq.in.

Sample Index Number	Av. parallel to the Rift Plane	Av. parallel to the rift Plane	Average	Average Range
1 LT.	5896	5880	5388	3500
2 LT.	6047	6068	6057	to
3 LT.	4228	4306	4267	6057
4 LT.	3432	3527	3479	

TABLE No. 51

Shear Strength
Lbs/Sq.inch

Sample Index Number	Av. parallel to Rift Plane.	Av. perpendicular to Rift plane	Average	Average Range
1 LT.	380	380	380	
2 LT.	415	405	410	312
3 LT.	405	400	402	to
4 LT.	315	310	312	410

TABLE No. 52

Transverse Strength
(Lbs/Sq.inch)

Sample Index Number	Strength value	Direction of Rift plane in relation to direction of bending.	Average Range
1 LT.	305	n.d.	297
2 LT.	383	n.d.	to
3 LT.	346	n.d.	383
4 LT.	297	n.d.	

TABLE No. 53.

LIMESTONES

Compressive Strength
(Lbs/Sq.inch)

Sample Index Number	Av. parallel to the Rift Plane	Av. perpendicular to the rift plane	Average	Average Range
1 LMST.	7,825	8,183	8,004	8000
2 LMST.	25,018	25,825	25,421	
3 LMST.	23,590	24,432	24,011	to
4 LMST.	10,790	11,254	11,022	25500
5 LMST.	9,250	9,738	9,494	
6 LMST.	14,186	14,714	14,450-	
7 LMST.	24,050	24,384	24,217	
8 LMST.	8,050	8,230	8,140	
9 LMST.	24,986	25,754	25,370	
10 LMST.	22,679	22,801	22,240	
11 LMST.	7,895	7,955	7,925	

TABLE No. 54.

Shear Strength
(Lbs/sq. inch)

Sample Index No	Av. parallel to the Rift Plane.	Av. perpendicular to the Rift plane	Average	Average Range
1 LMST.	957	1,008	957	
2 LMST.	3,485	3,515	3,500	
3 LMST.	3,068	3,157	3,112	
4 LMST.	1,635	1,675	1,655	
5 LMST.	1,207	1,239	1,273	957
6 LMST.	2,580	2,868	2,724	to
7 LMST.	3,102	3,304	3,203	3500
8 LMST.	1,150	1,306	1,228	
9 LMST.	3,409	3,533	3,471	
10 LMST.	3,107	3,205	3,156	
11 LMST.	1,175	1,225	1,200	

TABLE No. 55.

Transverse Strength
(Lbs/Sq.inch)

Sample Index Number	Strength Value	Direction of Rift plane in relation to Direction of Bending	Average range
1 LMST.	605	Parallel	
2 LMST.	1,904	Perpendicular	
3 LMST.	1,738	Perpendicular	600
4 LMST.	964	Parallel	to
5 LMST.	837	Perpendicular	
6 LMST.	1,523	Parallel	1950
7 LMST.	1,688	Parallel	
8 LMST.	765	Parallel	
9 LMST.	1,932	Perpendicular	
10 LMST.	1,805	Perpendicular	
11 LMST.	802	Perpendicular	

TABLE No.56.

GRANITE

Compressive Strength
(Lbs/Sq.inch)

Sample Index Number	Av. Parallel to the Rift Plane	Av. perpendicular to the rift plane	Average	Average Range
1 GR.	39,953	No rift plane	39,953	
2 GR.	30,955	-do- n.d.	30,955	
3 GR.	29,681	-do-	29,681	27,000
4 GR.	27,810	-do-	27,810	to
5 GR.	48,248	-do-	28,248	48,300
6 GR.	27,023	-do-	27,023	

TABLE No. 57.

Shear Strength
(Lbs/Sq.inch)

Sample Index Number	Av. parallel to the Rift plane	Av. perpendicular to the Rift plane	Average	Average Range
1 GR.	4224	No rift plane n.d	4224	
2 GR.	2945	"	3945	
3 GR.	3876	"	2876	3650
4 GR.	3908	"	3908	to
5 GR.	4850	"	4850	4900
6 GR.	3645	"	3645	

TABLE No. 58.

Transverse Strength
(Lbs/Sq.inch)

Sample Index Number	Strength value	Direction of the rift plane in relation to Direction of bending	Average Range
1 GR.	3298	No distinct rift	
2 GR.	3058	Planes	2400
3 GR.	Sample not sufficient	"	to
4 GR.	2380	"	4500
5 GR.	4205		
6 GR.	Sample not sufficient	"	

TABLE No. 59.

MISC. IGNEOUS ROCKS

Compressive Strength
(Lbs/Sq.inch)

Sample Index Number	Av. parallel to the rift plane.	Av. perpendicular to the Rift plane	Average	Average Range
1 BS.	48,801	No rift plane n.d.	48,801)	35,000 to 49,000
2 BS.	38,035	"	38,035)	
1 DL.	48,250	"	---	----
1 AT.	29,838	"	---	----
1 TT.	31,350	"	---)	31,300 to 35,000
2 TT.	34,280	"	---)	
1 DI.	36,650	"	---)	36,700 to 43,900
2 DI.	42,850	"	---)	
1 NO.	40,400	"	---	
1 GB.	38,358	"	---	General Range
1 SY.	45,048	"	---	14,000 to 49,000
2 GP.	39,876	"	---	
1 CH.	40,785	"	---	

TABLE No.60.

Shear Strengths
(Lbs/Sq.inch)

Sample Index Number	Av. parallel to the Rift Plane.	Av. perpendicular to the rift plane.	Average	Average Range
1 BS.	4932	No distinct rift planes.	-----	3600 to 4950
2 BS.	3808	"	-----	
1 DL.	4864	"	-----	
1 AT.	3055	"	-----	
1 TT.	3356	"	-----	3350 to 3950
2 TT.	3805	"	-----	
1 DI.	3780	"	-----	3800 to 4300
2 DI.	4268	"	-----	
1 NO.	4006	"	-----	General Range
1 GB.	3986	"	-----	3000
1 SY.	3855	"	-----	to
2 GP.	3608	"	-----	5000
1 CH.	4698	"	-----	

TABLE No.61,

Transverse Strength
(Lbs/Sq.inch)

Sample Index Number	Strength Value	Direction of the Rift plane in relation to direction of bending	Average Range
1 BS.	4738	No distinct rift Planes	4750 to 3400
2 BS.	3888	"	
1 DL.	4655	"	
1 AT.	2999	"	
1 TT.	3054	")	3050 to 3600
2 TT.	3598	")	
1 DI.	3600	")	3600 to 4000
2 DI.	3986	")	
1 NO.	3805	"	General Range
1 GB.	3775	"	3000
1 SY.	3622	"	to
2 GP.	3445	"	4800
1 CH.	4200	"	

TABLE No.62.

Marbles & Crystalline Limestones

Compressive Strength
(Lbs/Sq.inch)

Sample Index Number	Av. parallel to the rift Plane.	Av. perpendicular to the Rift plane	Average range
1 CL.	25,834	No distinct planes	16,000
2 CL.	24,500	"	to
1 MB.	21,040	"	26,000
2 MB.	26,316	"	
3 MB.	20,785	"	
4 MB.	21,018	"	

TABLE No.63.

Shear Strength
(Lbs/Sq.inch)

Sample Index Number	Av. parallel to the rift Plane	Av. perpendicular to the Rift Plane	Average Range
1 CL.	4558	No distinct Planes	2500
2 CL.	4275	"	to
1 MB.	2806	"	4600
2 MB.	3985	"	
3 MB.	2524	"	
4 MB.	3375	"	

TABLE No.64.

Transverse Strength
(Lbs/Sq.inch)

Sample Index Number	Strength value	Direction of Rift Plane in relation to Direction of Bending.	Average Range
1 CL.	4025	No distinct planes	2400
2 CL.	3996	"	to
1 MB.	2778	"	4000
2 MB.	3904	"	
3 MB.	2498	"	
4 MB.	3286	"	

TABLE No.65.

SLATES

Compressive Strength
(Lbs/Sq.inch)

Sample Index Number	Av. parallel to the Rift Plane.	Av. perpendicular to the rift plane	Average	Average Range
1 SL.	23,675	24,836	23,755	19,000
2 SL.	(See under Limestone 2 Lm.St)			to
3 SL.	22,356	23,986	23,171	25,000
4 SL.	23,008	23,406	23,207	
5 SL.	19,937	20,575	20,256	
6 SL.	23,537	23,858	23,697	

TABLE No.66.

Misc. Metamorphic Rocks

Compressive Strength
(Lbs/per sq.inch)

Sample Index Number	Av. parallel to the rift Plane.	Av.perpendicular to the Rift Plane	Average		Average Range
		No distinct rift Planes n.d.			
1 QZT.	35,375	"	-	29041	3000 to 35000
2 QZT.	32,032	"	-		
3 QZT.	29,786	"	-		
4 QZT.	28,975	"	-		
1 GN.	30,286	34,325	32305	30158	
2 GN.	27,955	28,067	28011		
1 PH.	3,896	4,508	4202	8907	
2 PH.	5,275	5,505	5390		
3 PH.	8,038	8,406			
1 SCH.	3,537	3,605	3571		
kH.	20,856	No distinct plane	-		
CCL.	15,148	"	-		

TABLE No.69.

Shear Strength
Lbs/Sq.inch

Sample Index Number	Av. parallel to the Rift Plane.	Av. perpendicular to the Rift Plane.	Average	Average Range
		No distinct Plane of rift n.d.		
1 QZT.	5035	"	-	
2 QZT.	4706	"	-	250
3 QZT.	4804	"	-	to
4 QZT.	5055	"	-	6000
			4597	
1 GN.	3858	3906	3882	
2 GN.	3175	3425	3300	
			3591	
1 PH.	250	1680	965	
2 PH.	305	1756	1030	
3 PH.	286	1598	942	
			979	
1 SCH.	475	1804	1139	
1 KH.	2258	-	-	
1 CCL.	1983	-	-	

TABLE No.70.

Transverse Strength

Strength Value
Lbs/Sq.inch.

Sample Index Number	Strength Value	Direction of Rift Plane in relationto direction of bending	Average Range
		No rift plane n.d.	
1 QZT.	4875	"	
2 QZT.	4538	"	1500
3 QZT.	4368	"	to
4 QZT.	5006	"	5100
1 GN.	3506	Perpendicular	
2 GN.	2635	Perpendicular	
1 PH.	1575	Perpendicular	
2 PH.	1698	Perpendicular	
3 PH.	1507	Perpendicular	
1 SCH.	1872	Perpendicular	
1 KH.	1986	No distinct plane	
1 CCL.	1875	No distinct plane	

TABLE No.71.

DISCUSSIONS AND CONCLUSIONS

Compressive Strength :-

It is well known that the common stones are very strong and durable building materials. No stone which is likely to be used in any engineering project will ever fail under the crushing loads. Further, a small test piece under a testing machine may fail at a particular load but in actual practice it is incrushable. Inspite of these facts, we find that the most common test carried out for the evaluation of a building stone is the crushing strength. This is performed as it gives certain engineering information which readily acts as a factor of comparison in the case of stones of different origin and composition. Since slates are not used as masonry material for walls etc. the compressive strength is not so significant as much as the modulus of rupture. From these points of view the relationship of the compressive strength and other engineering as well as physical properties have been studied and discussed.

It has been observed during these tests that the cubes of the same rock such as Dholpur Sandstone and Bhulvan Granite having the same size, shape and character of bearing surfaces failed under different loads. In order to establish this actual cause of these variations more experiments need to be performed in each case. However, in all probabilities the cause of these variations lies in either of the following :

a) Faulty method of quarrying

b) Distribution of microcracks and incipient planes of cleavages in stone and their relation to load distribution.

c) The degree of dryness of stone.

d) Seasoning time. What is meant by this?

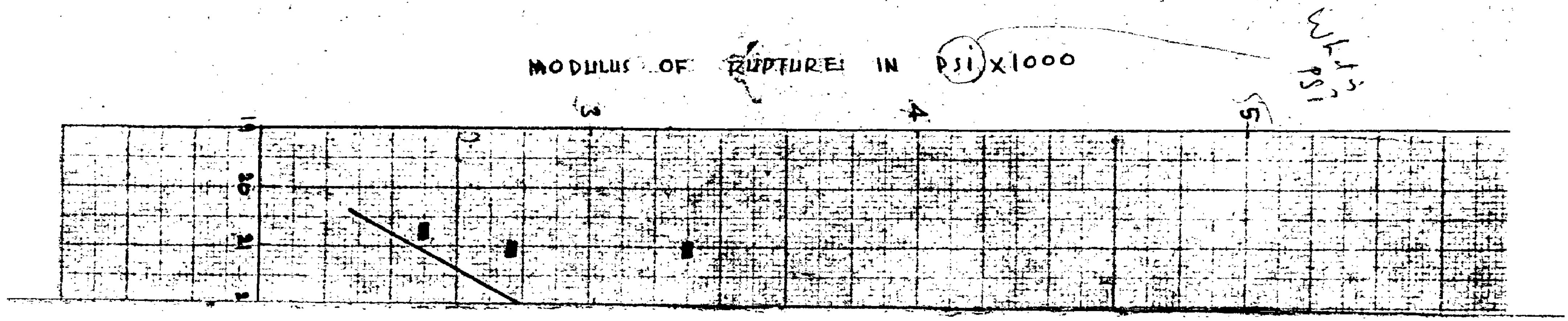
e) The degree of weathering.

Modulus of Rupture.

As stated above, an attempt has been made to ascertain if there is any relationship between the compressive strength and modulus of rupture in case of 'Indian Building Stones'. Graphs have been plotted (Figs. 20,21 & 22) seperately for the two values i.e. along and across the rift planes. From a study of these graphs there appears to be a close relationship between these two properties, but the degree of variation is quite different from rock to rock. For example, the curve of relationship in case of sandstones is quite different from that of limestones or granites (Fig. 22 to 22). Hence, no ? general curve can be drawn and each variety of roc' has to be referred to its own curve for this relationship.

Shear Strength.

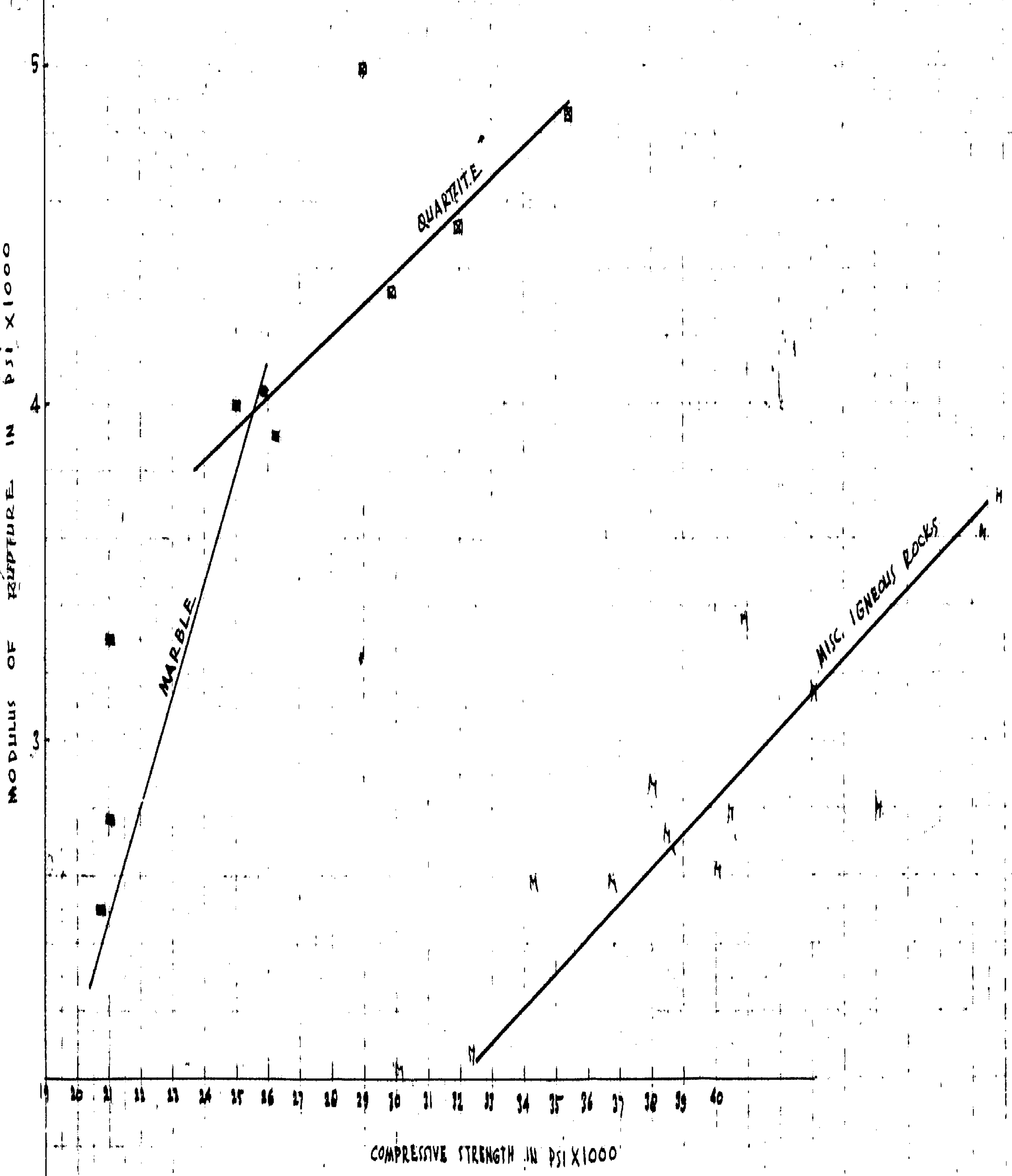
Similarly the relationship between cc and the shear strength have been shown ir In this case also the value for the she pendicular to the rift planes have be



MODULUS OF RUPTURE IN PSI X1000
What's PSI
3
4
5
20
21

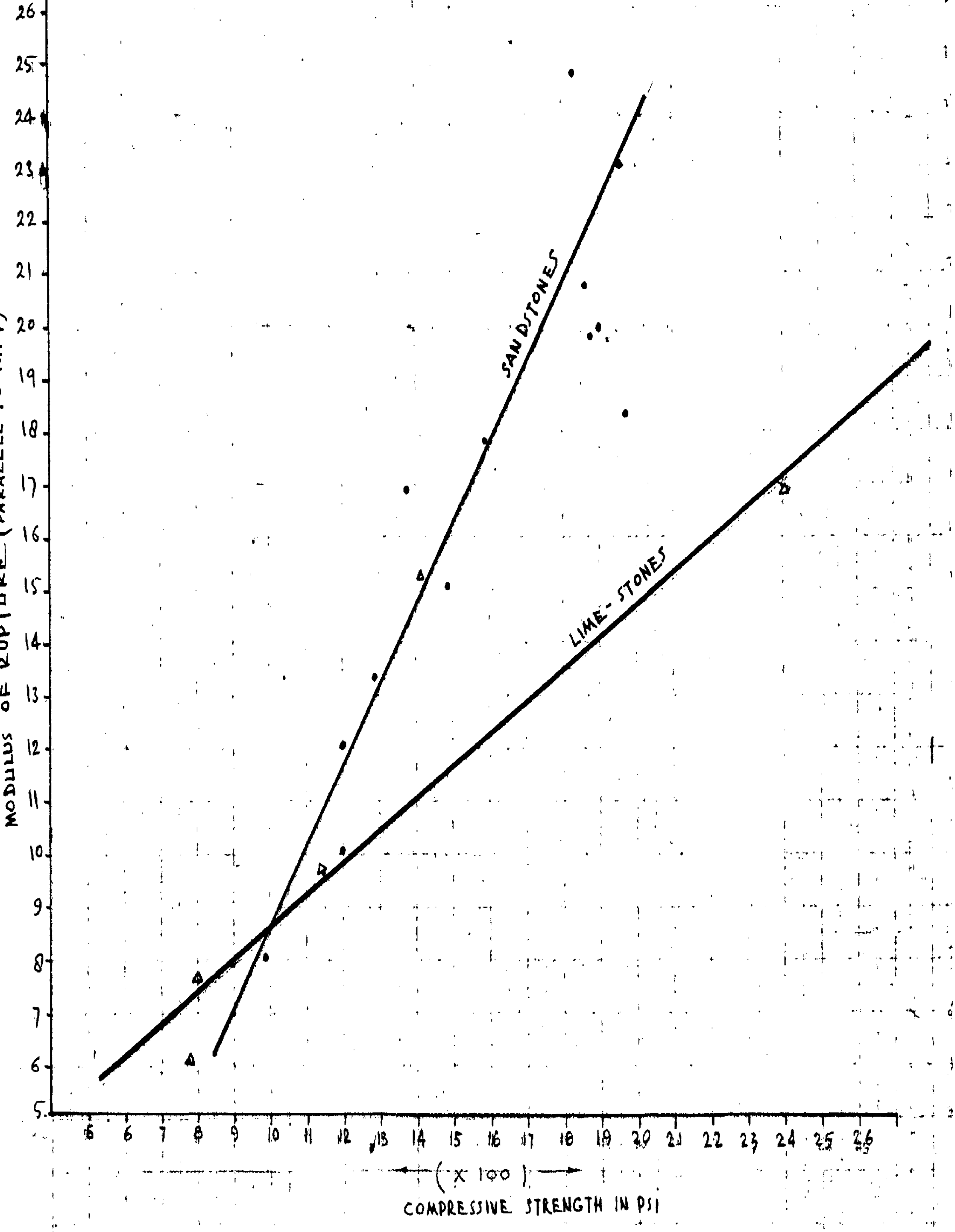
COMPRESSIVE STRENGTH Vs. MODULUS OF RUPTURE

FIG. 20



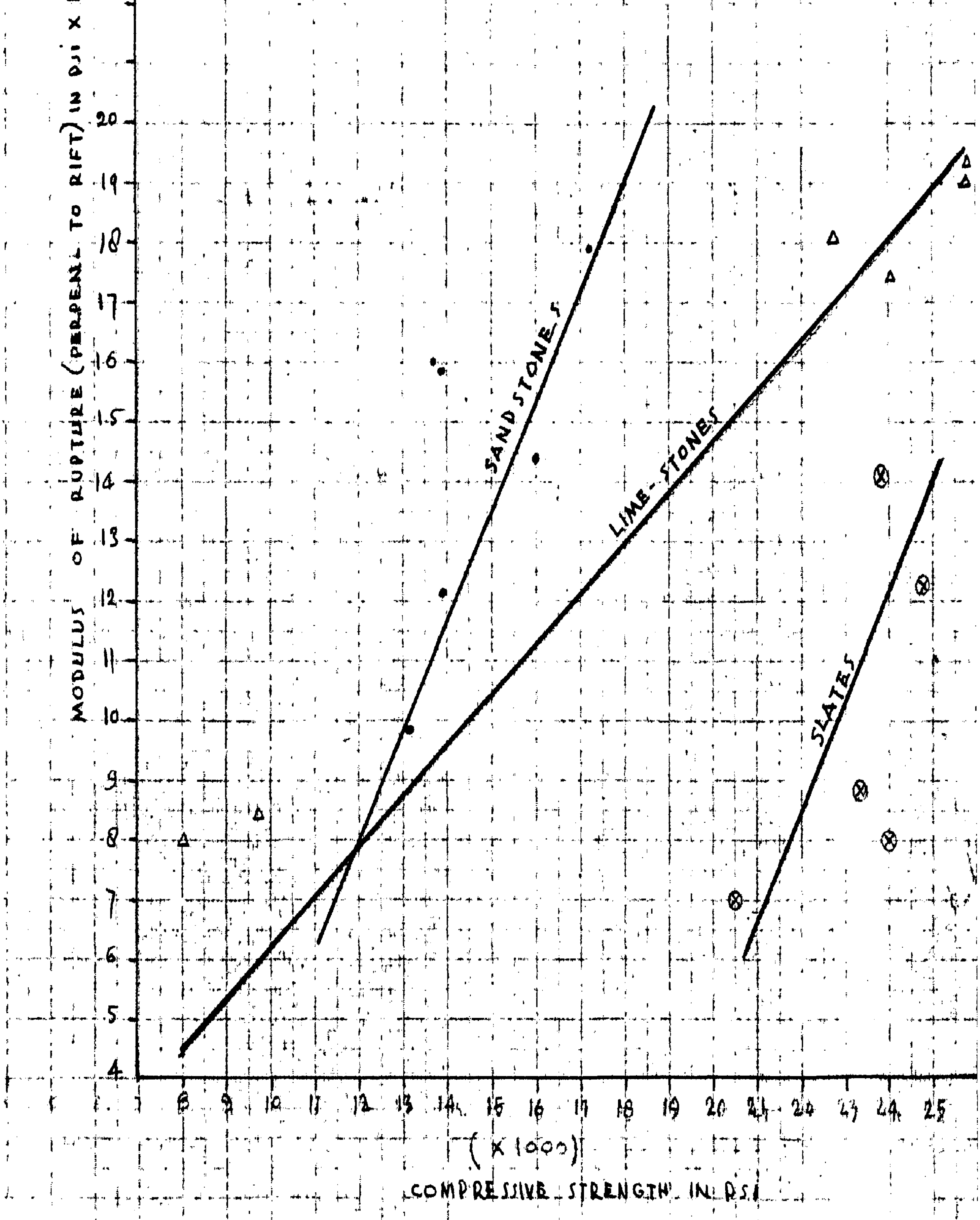
COMPRESSIVE STRENGTH Vs. MODULUS OF RUPTURE

FIG. 21



COMPRESSIVE STRENGTH Vs. MODULUS OF RUPTURE

FIG. 22



and each type of stone has a curve of its own.

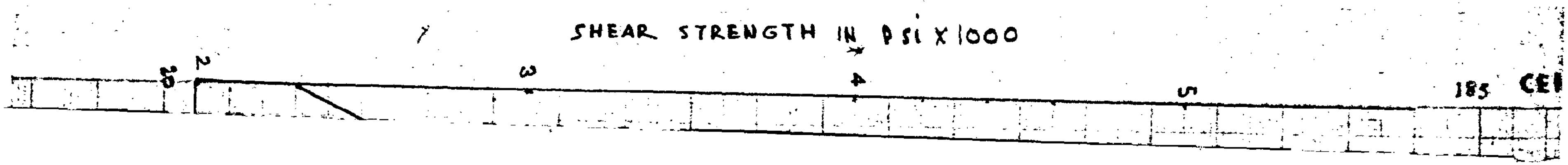
From the above two relationships it can be safely concluded that the relationship between the modulus of rupture and the shear-strength can best be known through compressive strength and not directly from these curves.

A NUMERICAL CLASSIFICATION FOR INDIAN STONES.

The purpose of any classification is to place certain numbers of a particular family in one group depending upon their similarity in as many aspects as possible. Similarly, an attempt has been made to classify the different 'Building Stones' in various classes where each class broadly signifies the physico-engineering properties of the stones belonging to that particular class.

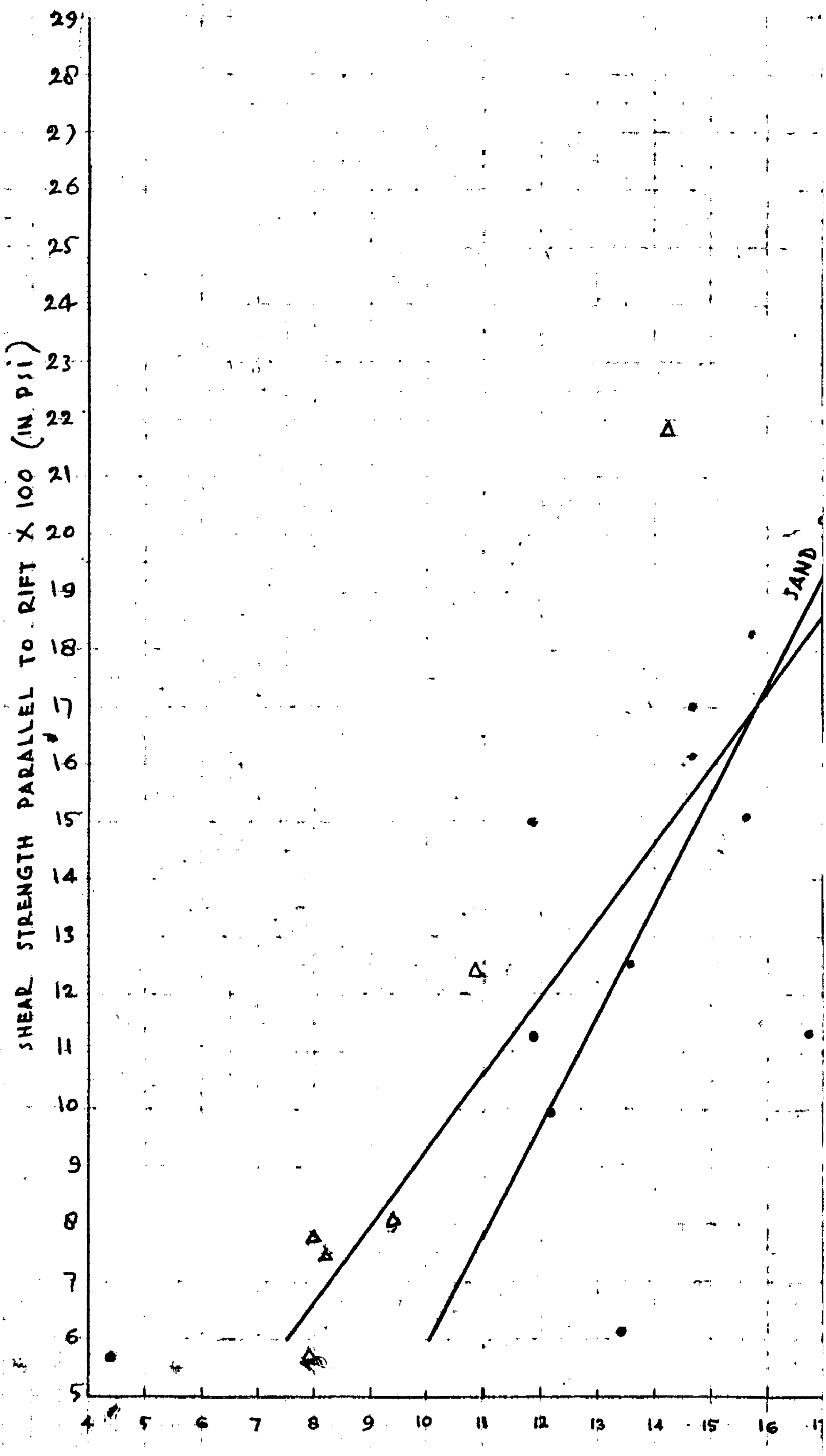
This is done for the purpose of trade and commerce in addition to its use in engineering terminology. For example, a granite belonging to 'Hardness No.12' means that its compressive strength lies between 36,000 to 40,000 p.s.i. and wt/cu.ft. is in between 175.25 and 176.25.

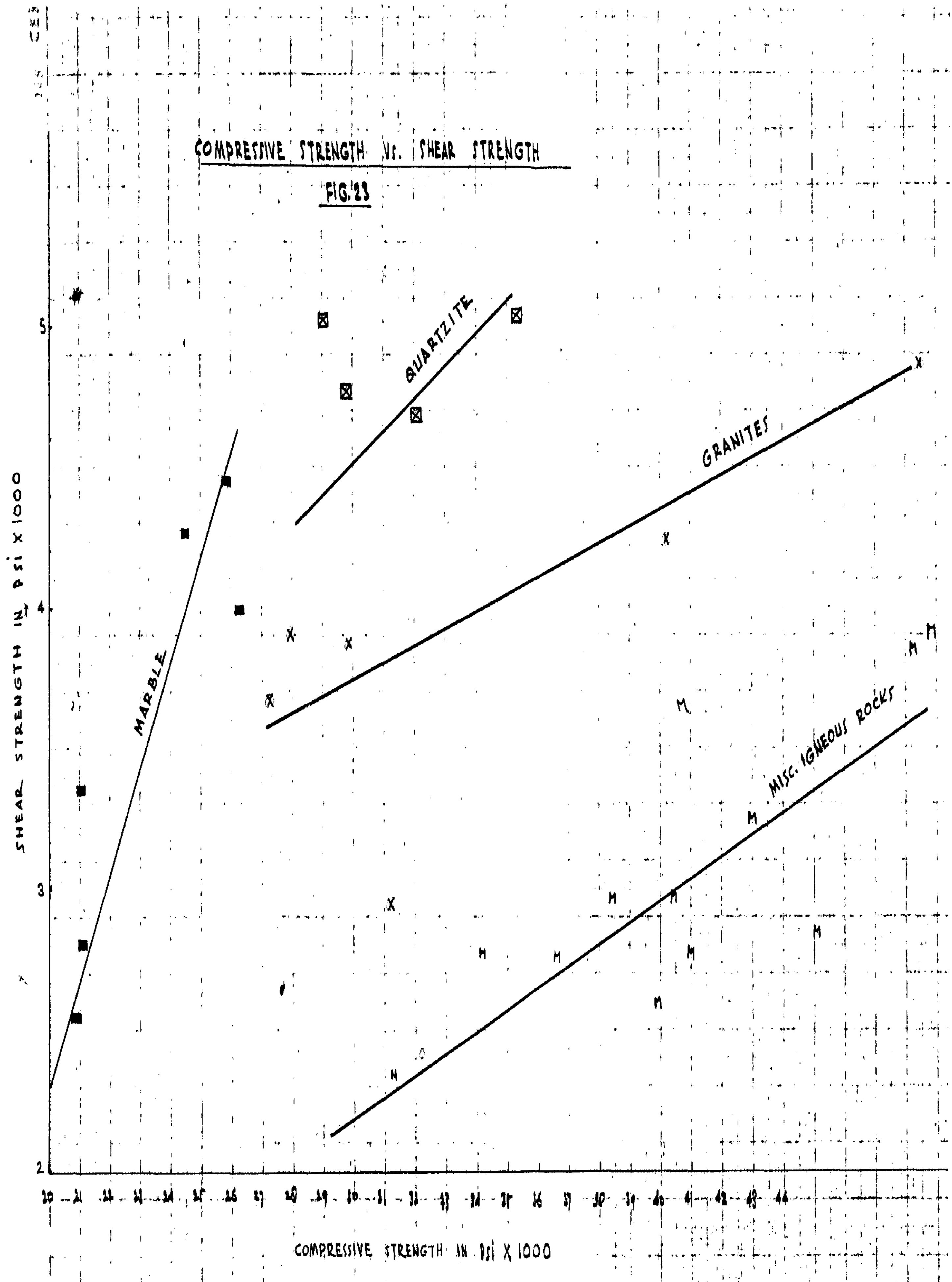
A similar classification which is quite unique and singular in nature so far has been proposed by the French Standards[46]. It refers only to calcareous rocks which are devided into 14 classes on the basis of the relationship between modulus of rupture and density. However, this does not satisfy the purpose and as reported by Mr. Demare[47], a fresh classification with a different basis is being attempted in France also.


SHEAR STRENGTH IN psi X 1000
20
2
3
4
5
185
CE

COMPRESSIVE STRENGTH Vs. SHEAR STRENGTH (ALONG

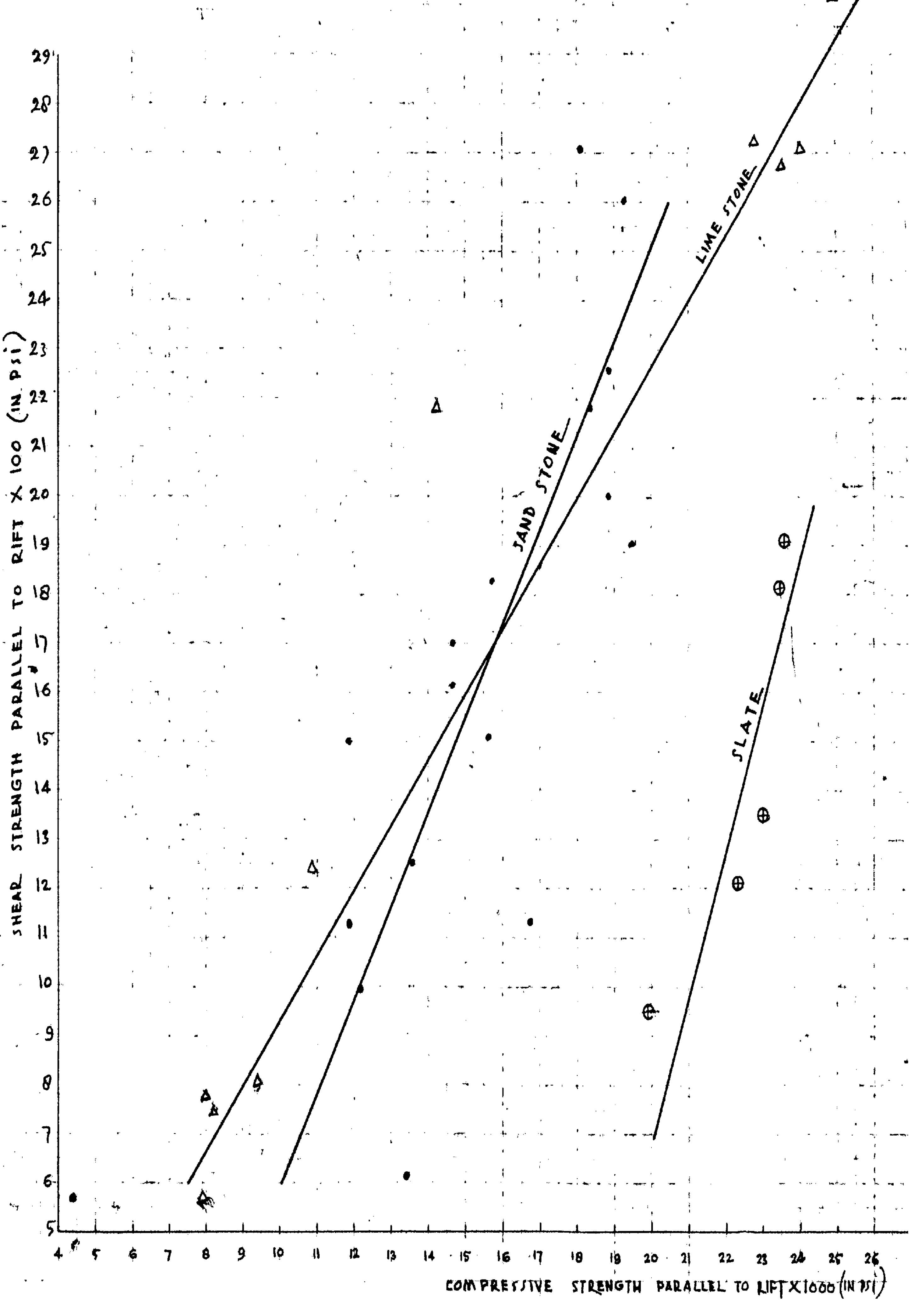
FIG. 24

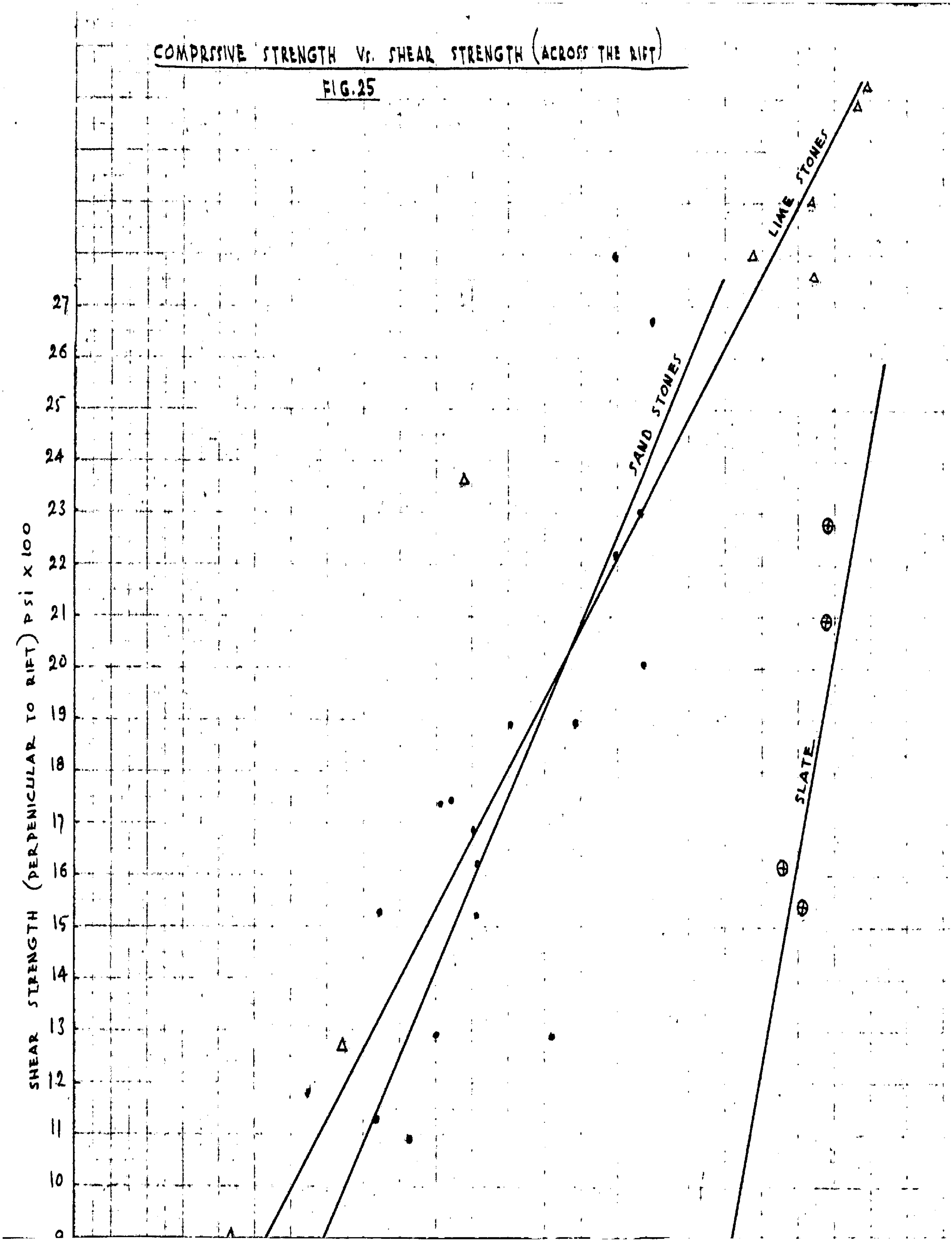



COMPRESSIVE STRENGTH Vs. SHEAR STRENGTH
FIG. 23
QUARTZITE
GRANITES
MARBLE
MISC. IGNEOUS ROCKS
SHEAR STRENGTH IN psi X 1000
COMPRESSIVE STRENGTH IN psi X 1000
2
3
4
5

COMPRESSIVE STRENGTH Vs. SHEAR STRENGTH (ALONG THE RIFT)

FIG. 24




COMPRESSIVE STRENGTH Vs. SHEAR STRENGTH (ACROSS THE RIFT)
FIG.25
SHEAR STRENGTH (PERPENDICULAR TO RIFT) PSI x 100
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
LIME STONES
SAND STONES
SLATE

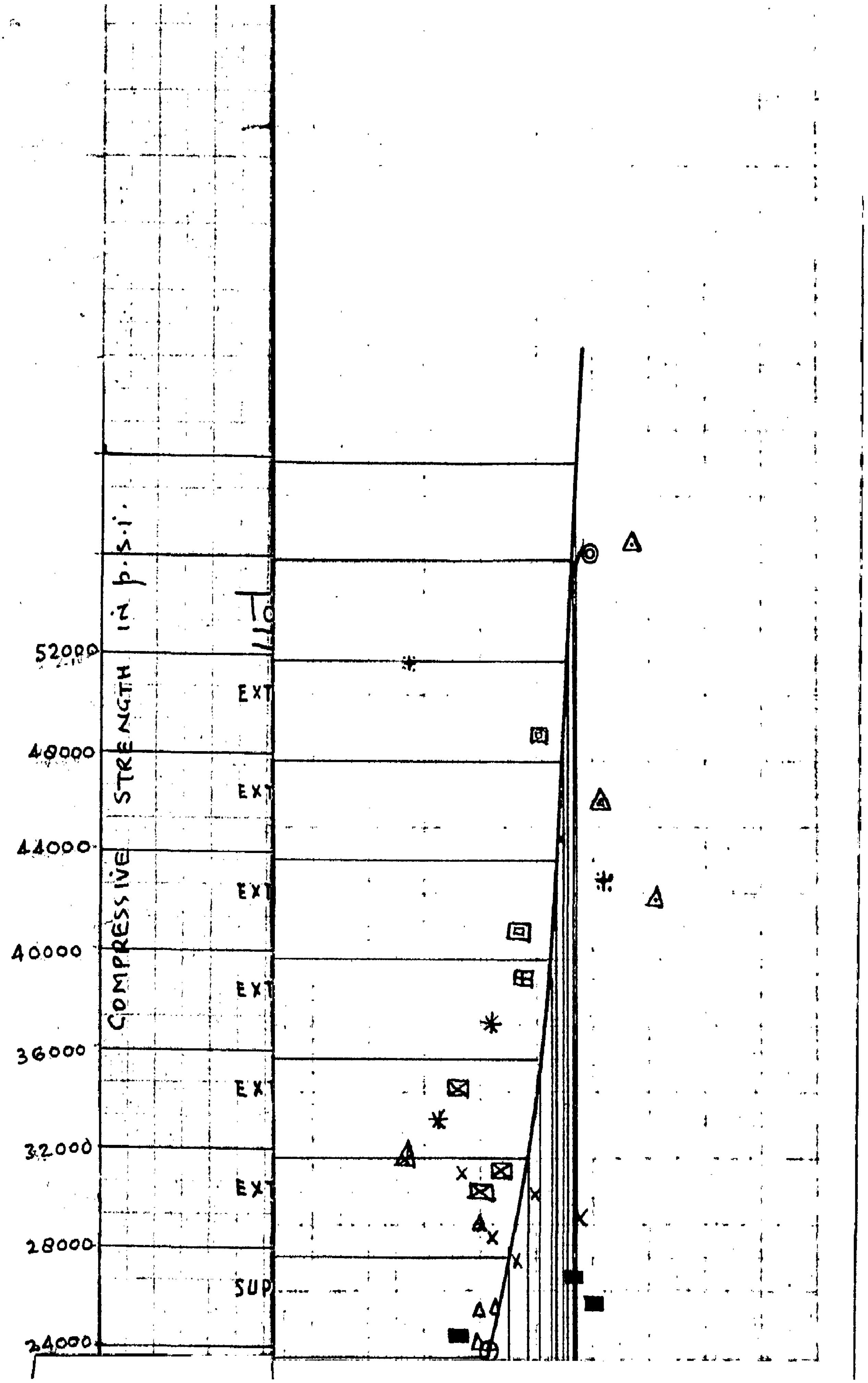
Principal Basis of Classification

It is well known that the chief characteristic for the utilization of stones is their resistance to failure. Further, it has also been observed that in the trade of building stones in this country, the quality of a stone, its price, and the rate at which it is likely to be cut and dressed is decided by the wt/cu/ft. The higher the wt/cu/ft. the lower the cutting rate. Hence, an attempt has been made to establish a general relationship between the engineering properties and the physical properties of rocks on the basis of which a new scheme of classification is proposed.

It has been concluded that the compressive strength gives a fair idea about the modulus of rupture and the shearing strength of a rock. Further, it has also been seen that the apparent specific gravity is closely related to the wt/cu/ft of a rock.

The results of the compressive strength of the rocks tested and used as 'Building Stones' were plotted in a graph along Y-axis against the wt/cu/ft. The compressive strength parallel and perpendicular to the rift planes have been averaged for the purpose of this classification. From the trend of the points on graph (Fig. 26) it has been observed that the points lie along a curve of the type of a rectangular hyperbola as shown in figure 26.

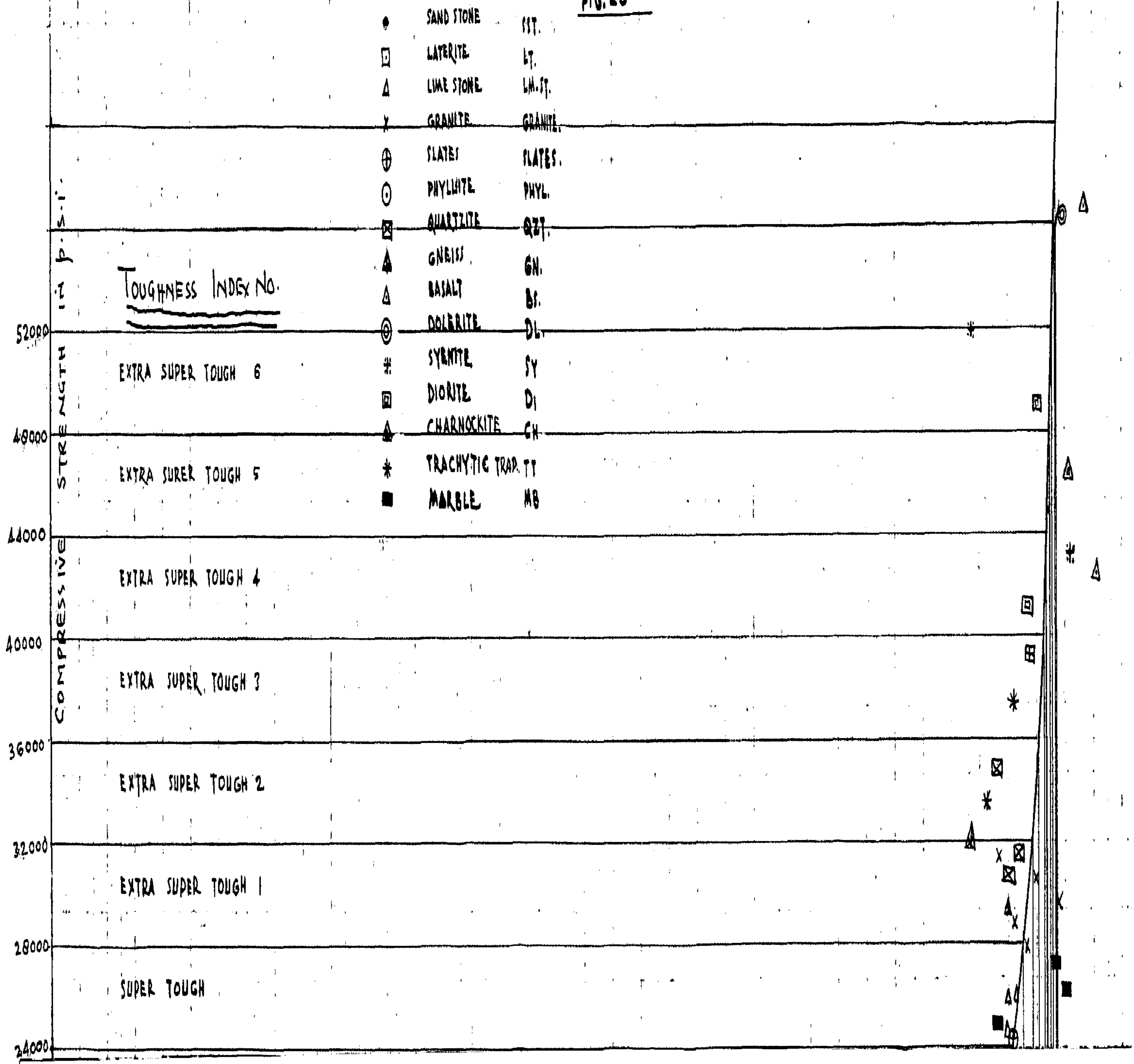
The equation derived for the governing law of variation of these two characteristics is :



COMPRESSIVE STRENGTH in p.s.i.
52000
48000
44000
40000
36000
32000
28000
24000
EXT
EXT
EXT
EXT
EXT
EXT
SUP

NUMERICAL CLASSIFCATION FOR INDIAN BUILDING STONES.

FIG. 26



$$C = \frac{5 \times 10^5}{195 - W}$$

where C = compressive strength in p.s.i.

W = Weight per cubic foot.

On the basis of the above law of variation, the rocks have been classified in general and are given in table No. 72.

From the figure 26 it is clear that as the compressive strength increases the range of the Wt/Cu/ft. becomes narrow and narrow till such time when the general curve becomes parallel to the Y-axis.

Utilization of the classification

Though it is possible to correlate the other engineering properties like modulus of rupture and shearing strengths with wt/cu/ft. it has not been done because the correct assessment of properties on the basis of curves obtained by the correlation of physical properties of each type of rock with other engineering properties, can only be done after the compressive strength is known.

For example, having known the Wt/cu/ft. it is possible to get theoritically the compressive strength of a stone approximately. From the compressive strength the correct assessment of other two properties like modulus of rupture, and shearing strength can only be done by referring to the respective curves (Fig. 20 to 25). These respective curves are different in case of each type of rock.

Classification of Building Stones

Hardness No.	Nature of Hardness	Compressive Strength in p.s.i.	Rock Types
1	Very Soft	0 to 3000	Sand, Mud, Clay, Loose shales etc.
2	Soft	3000 to 6000	Laterites, friable sandstones.
3	Demi Firm	6000 to 9000	Sandstones and Limestones.
4	Firm	9000 to 12000	-do- -do-
5	Very Firm	12000 to 15000	-do- -do-
6	Demi Tough	15000 to 18000	Sandstones, Limestones and Phyllites.
7	Tough	18000 to 21000	Compact Sandstones and Limestones and Phyllites.
8	Very Tough	21000 to 24000	Hard sandstones, Slates and Phyllites.
9	Super Tough	24000 to 28000	Slates, compact limestones and slates and Marbles
10	Extra Super Tough 1	28000 to 32000	Granites, Quartzites, Marble Gneisses.
11	-do- 2	32000 to 36000	Granite, syenites, charnockites.
12	-do- 3	36000 to 40000	Granites, Basalts Dolerites
13	-do- 4	40,000 to 44000	-do- -do- -do-
14	-do- 5	40,000 to 48000	-do- -do- -do-
15	-do- 6	48000 and more	-do- -do- -do-

TABLE No. 72.

above would be more appropriate

Limits of wt/cu.ft. should have also been tabulated here.

Hence, this classification should be treated as a general classification and should not be extended to all other physical and engineering properties such as modulus of rupture or shearing strengths directly. Such an attempt would obviously mean a declassification.

Average Engineering Properties

For the sake of simplicity the average ranges of the engineering properties in case of the 'Building Stones' have been briefly summarized in the following table on next page.

Nature of Rock	Compressive Strength p.s.i.		Shear Strength p.s.i.		Modulus of
	Average (parallel to the Rift)	Average (perpendicular to Rift.	Av. (Parallel to Rift)	Av. Perpendicular to Rift.	Av. parallel to rift.
Sandstones	4369 to 19,687	4501 to 20,011	568 to 2709	605 to 2803	504 to 2475
Laterite	3432 to 6,047	3527 to 6068	3527 to 6068	315 to 405	297 to 383
Limestone	7825 to 25,018	7955 to 25,825	957 to 3485	1008 to 3533	605 to 1932
Granite	27023 to 48,248	(no rift Plane)	2945 to 4850	(No Rift Plane)	2380 to 4205
Basalt	38035 to 49,000	(No rift Plane)	3608 to 4932	-do-	3888 to 4738
Dolerite	48250	-do-	4864		
Diorite	36650 to 42850	-do-	3780 to 4268	-do-	3600 to 3986
Marbles	20785	-do-	2524 to 4558	-do-	2948 to 4025
Slates	19937 to 23675	20575 to 24836	2453 to 3294	2685 to 3658	9668 to 14045
Quartzites	28975 to 35375	(No Rift Plane)	4706 to 5055	(No rift plane)	4368 to 5006
Gneiss	27,955 to 30,286	28067 to 34325	3175 to 3858	3425 to 3906	2635 to 3506
Phyllites	3895 to 8038	4505 to 8406	250 to 305	1598 to 1756	1507 to 1898

TABLE No.73.

CHAPTER VII.

ULTRASONIC & SONIC PROPERTIES OF INDIAN BUILDING STONES

'Dynamic Modulus of Elasticity' is an important property in case of building materials. The conventional mechanical methods of determining the dynamic modulus of elasticity does not explain the causes of variation in test results obtained in case of similar rock types. The influence and the relationship of the physical, chemical, engineering and the petrographic characteristics of the materials with their modulus of elasticity could not be studied by these methods. Hence, the use of 'Ultrasonic' and 'Sonic' methods of determining the modulus of elasticity has been adopted recently[48,49].

Ultrasonic Properties.

Ultrasonic waves (waves of a frequency more than about 20,000 cycles) have become of great importance in recent years. Their unique properties have been applied to the industrial testing, signaling, medicine and rock drilling etc.[48,49].

The propagation of the mechanical waves in solids in general has been studied theoritically for many years. It is now well known that three types of plane waves can be transmitted by the unbounded medium. In isotropic materials these are (a) longitudinal wave with particle motion along the directi of propagation, (b) two shear waves with particles motions perpendicular to the direction of the propagation. In an anisotropic material these three waves are also propagated but the particle velocities are not usually along or at right angles to the direction of the propagation so that no wave is strictly longitudinal or transverse.

Bounded media transmits waves at velocities which depend on the mode of transmission, the frequencies of excitation, the elastic constants and the dimensions of the sample. The frequencies are usually above the audible range and therefore this name Ultrasonics has been applied to this field of work[48,49]. The study of wave propagation and the interpretation of velocity that is measured in the media will throw light on the mineralogic petrographic, physical and engineering properties of rocks used as building stones. The velocities depend not only on the elastic and physical constants, but also on grain structure and other petrographic characteristics of rocks under test.

The ultrasonic pulse velocities in the longitudinal mode of propagation have been determined and are given in table No.74.

SONIC PROPERTIES

'Sonic' is the technology of sound as applied to problems of measurement, control and processing. It encompasses the analysis testing, and processing of materials and products by the use of mechanical vibration energy. Hence by this technique we can measure elastic constants of solids and nonisotropic stresses and inhomogenieties can be analyzed. Bad language

The dynamic (Sonic) modulus of elasticity is an important property of a material for building purposes. The apparatus and the method of study of this property has been dealt with in chapter IV. The fundamental resonance frequencies in the transverse mode of vibration and the sonic modulus of elasticity as determined in case of the Indian rocks are given in table No.75.

ULTRASONIC PROPERTIES OF INDIAN BUILDING STONES

Sample Index Number	Nature of Rock and Locality.	Length in inches	Breadth in Inches.	Width in inches	Time of travel of ultrasonic pulse in length M/Sec.	P density lb/cu.ft	Velocity 'V' ft/sec.	'E' in lb/sq.in.	Remark.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SEDIMENTARY									
1.	Sandstone (Dholpur)	$7\frac{14}{16}$	2	$2\frac{1}{16}$	56	141.35	11,720	4.21×10^6	Samples cut and dressed by the suppliers.
2.	Sandstone (Mirzapur) Red.	$8-\frac{1}{16}$	$1-\frac{15}{16}$	$1\frac{14}{16}$	44	164.68	15,270	8.33×10^6	
3.	Sandstone Pale (")	$8-\frac{2}{16}$	$1-\frac{15}{16}$	2	47	152.30	14,410	5.43×10^6	
4.	Limestone (Ramganjmandi)	$7\frac{15}{16}$	2	$1-\frac{14}{16}$	32.5	178.6	20,350	16.4×10^6	
5.	Limestone (Jaisalmer)	$14-\frac{2}{16}$	$\frac{14}{16}$	$1-\frac{3}{16}$	86	145.7	13,690	5.90×10^6	
IGNEOUS									
6.	Granite (Dodballabpur)	$8-\frac{3}{16}$	$1-\frac{13}{16}$	$2-\frac{1}{16}$	41	170.5	16,640	10.24×10^6	
7.	Granite (Andhra)	$8-\frac{2}{16}$	$1-\frac{14}{16}$	2	42.5	186.30	15,930	10.26×10^6	
8.	Granite (Bangalore)	$8-\frac{4}{16}$	2	2	-	195.1	21,050	$25.5a \times 10^6$	
9.	Syenite (Mandya)	5	2	$2-\frac{1}{16}$ "	22	157.3	18,940	12.26×10^6	
10.	Diorite (Mangalore)	$4-\frac{15}{16}$	2	2	24	169.7	17,140	10.81×10^6	

CONTD.

Table No; 74.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10
11.	Gabbro (Maddur)	5	2	2	20	190.5	19,960	16.47×10^6	
12.	Dolerite (Berasia)	5	2	2	20	199.04	20,830	18.74×10^6	
13.	Basalt (Bhopal)	7- $\frac{5}{16}$	2- $\frac{1}{16}$	2- $\frac{1}{16}$	35	192.4	18,900	14.91×10^6	
	METAMORPHIC								
14.	Quartzite (Dodaballabpur)	5	2	2- $\frac{1}{16}$	23	167.20	18,110	11.90×10^6	
15.	Slate (Kurnool)	5	2	2	20	163.88	20,830	15.42×10^6	
16.	Marble (Makrana)	12	1	1	62	181.1	16,130	10.22×10^6	
17.	Marble (Baislana)	12	$\frac{15}{16}$	$\frac{12}{16}$	52	184.8	19,230	14.83×10^6	
18.	Marble (Kishangarh)	11- $\frac{10}{16}$	1	$\frac{13}{16}$	56	194.7	17.300	12.64×10^6	
19.	Marble (Kishangarh)	12	1- $\frac{1}{16}$	$\frac{13}{16}$	52	187.6	19,230	15.05×10^6	
20.	Serpentine (Mysore)	5- $\frac{12}{16}$	2	2- $\frac{1}{16}$	46	125.6	9,280	2.34×10^6	
21.	Gneiss (Bangalore)	4- $\frac{15}{16}$	2	2	24	170.7	17,140	10.81×10^6	

TABLE No.74.

SONIC MODULUS OF ELASTICITY OF INDIAN BUILDING STONES

Sample Index Number	Nature of Rock & Locality	Length in inches	Breadth in inches	Width in inches	Natural frequency in transverse mode of vibration.	Elasticity $lbs \times 10^6$/sq.inch	Remarks
SEDIMENTARY							
1.	Sandstone (Dholpur)	$7\frac{14}{16}$	2	$2\frac{1}{16}$	3490	3.93	Samples cut and dressed by the suppliers.
2.	Sandstone Red (Mirzapur)	$8\frac{1}{16}$	$1\frac{15}{16}$	$1\frac{14}{16}$	4200	5.80	
3.	Sandstone Pale (Mirzapur)	$8\frac{2}{16}$	$1\frac{15}{16}$	2	3650	4.36	
4.	Limestone (Ramganjmandi)	$7\frac{15}{16}$	2	$1\frac{14}{16}$	5980	13.09	
5.	Limestone (Jaisalmer)	$14\frac{2}{16}$	$\frac{14}{16}$	$1\frac{3}{16}$	700	5.40	
IGNEOUS.							
6.	Granite (Dodaballapur)	$8\frac{3}{16}$	$1\frac{13}{16}$	$2\frac{1}{16}$	5200	9.30	
7.	Granite (Andhra)	$8\frac{2}{16}$	$1\frac{14}{16}$	2	5120	9.91	
8.	Granite (Bangalore)	$8\frac{4}{16}$	2	2	6100	16.48	
13.	Basalt	$7\frac{15}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}$	6000	16.78	
METAMORPHIC.							
16.	Marble (Makrana)	12	1	1	1540	13.78	
17.	Marble (Bhaislana)	12	$\frac{15}{16}$	$\frac{12}{16}$	1570	15.42	
18.	Marble (Kishangarh)	$11\frac{10}{16}$	1	$\frac{13}{16}$	1490	12.18	
19.	Marble (Kishangarh)	12	$1\frac{1}{16}$	$\frac{13}{16}$	1780	16.86	

TABLE No.75.

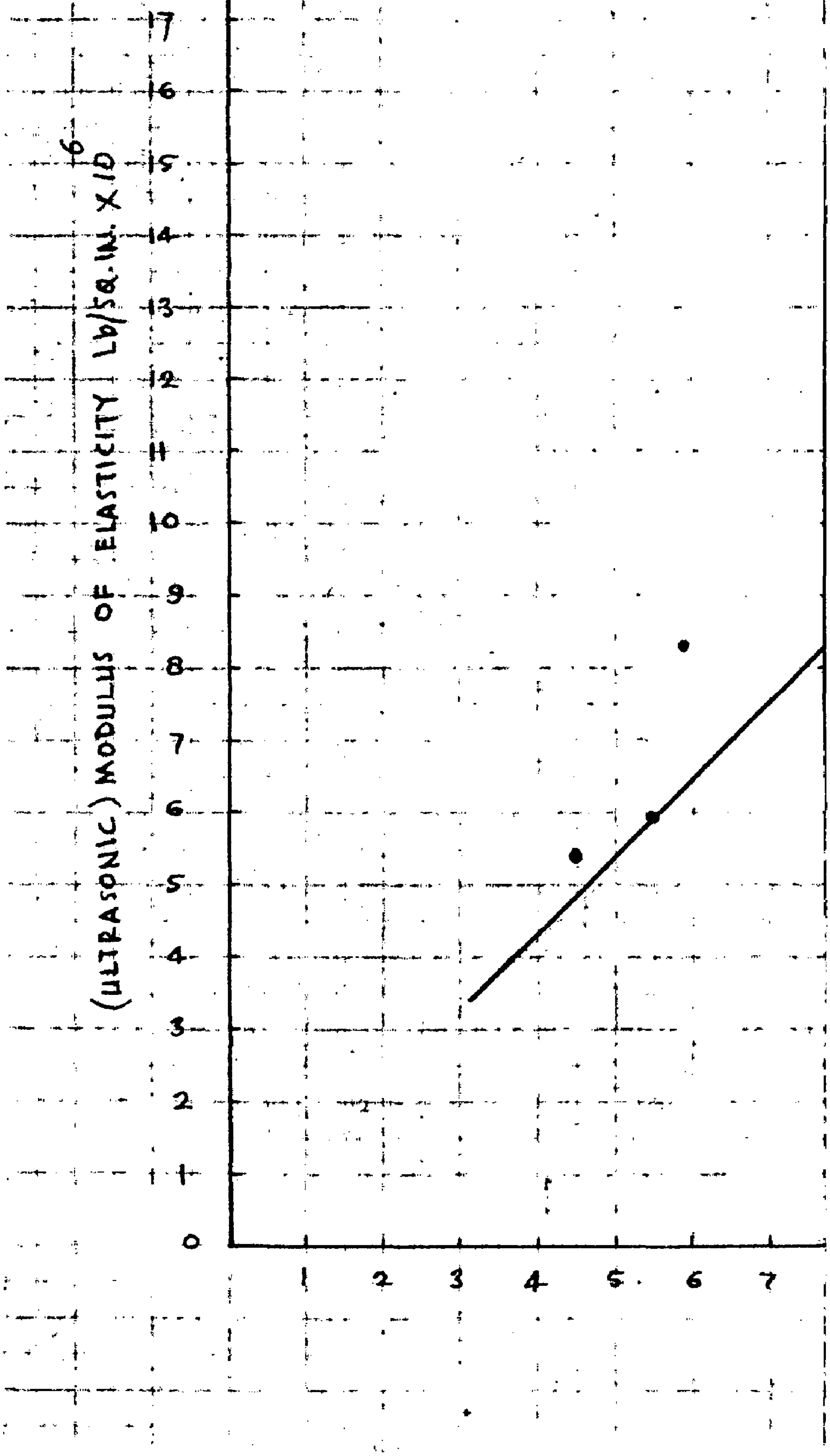
DISCUSSIONS AND CONCLUSIONS

With a view to compare the results of elasticity obtained by the 'Ultrasonic' and 'Sonic' methods, a graph was plotted (Fig.27). From the relationship obtained it is evident that there is a close coincidence between the results obtained by these two different techniques.

However, it has been seen that certain point such as No. 2, 4, 13, 16, 17 and 19 corresponding to Sandstone from Mirzapur, Limestone from Ramganjmandi, Basalt from Bhopal, Marbles from Makrana, Bhaislana and Kishangarh respectively, do not follow the general trend of the curve. In case of a limestone from Ramgangmandi the deviation may be due to the flaggy nature of the stone. In such cases the velocity is effected at the parting surfaces. In case of red sandstone from Chunar (point No.4) the low values of sonic modulus of elasticity and are perhaps due to the fact that the samples were cut perpendicular to the bedding plane and the transverse mode of vibrations are bound to give low values in such cases. Basalt from Bhopal (13) was slightly weathered and the plagioclase laths showed marked alternation of their grain boundaries. The clay minerals so formed at the boundaries generally reduce the frequency of vibration in case of ultrasonic pulses. Marbles from Makrana, Bhaislana and Kishangarh (16, 17 and 19) have randomly distributed cleavage directions of Calcite crystals and it appear that these differences in cleavage directions have effected the ultrasonic wave velocities. On the other hand in case of transverse

ELASTICITY (SONIC) Vs. ELASTI

FIG. 27



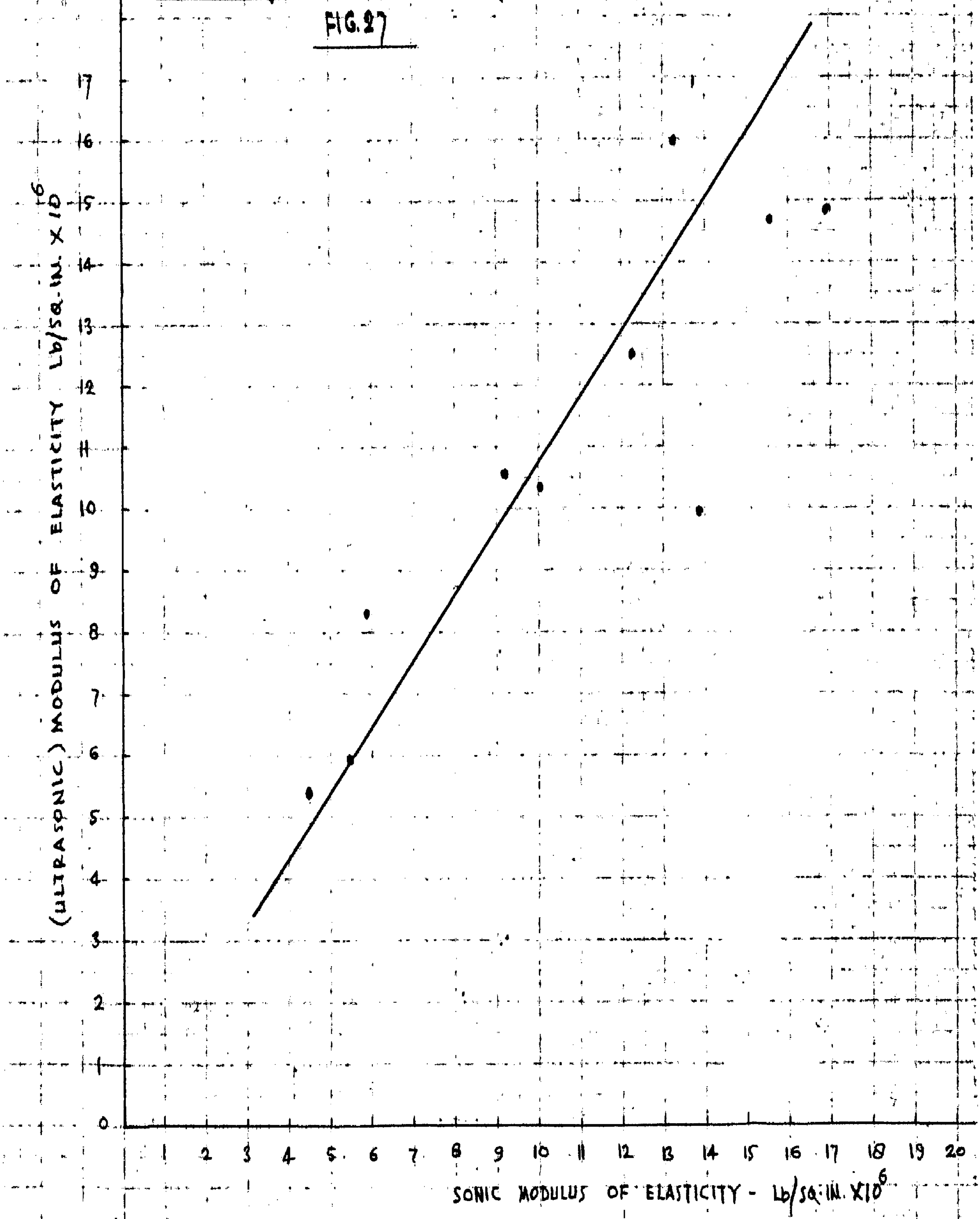
mode of vibrationsmmd the whole mass not only behaves as one but perhaps the interlocking of grains helps in giving higher values.

Further to show the influence of the physical properties like density on elasticity and the ultrasonic pulse velocity, graphs showing the relationships have been plotted (Fig. 28 and 29). From the curves obtained, it is clear that there is a close relation between these two important properties. Deviation of points 4, 7, 9, 14, 15, 16 and 18 corresponding to Limestone, Granite, Syenite, Quartzite, Slate, Marbles respectively, is indicative of the difference in the inherent characteristics of these materials. Limestone (4) is a very compact and fine grained rock. As the ultrasonic pulse velocities travel at a higher rate in homogenous continuous media, it is expected that the velocity in limestone like the one tested here will give higher velocities. Coarse grained hetrogeneous mass will always retards the ultrasonic velocities. Similarly Granite from Andhra Pradesh (7) has shown low frequencies as compared to its wt/cu.ft. Propagation of waves is effected by the crystal boundaries also. Again in case of sedimentary quartzite from Bangalore (14), the quartz grains being in optical continuity with each other makes it a solid homogeneous mass and therefore has given higher values. Similarly Syenite (9) has acted in an expected manner.

In case of Slates the position as has been observed here is slightly different. Two different velocities have been noted in two different directions. It was observed that the

ELASTICITY (SONIC) Vs. ELASTICITY (ULTRASONIC).

FIG. 27



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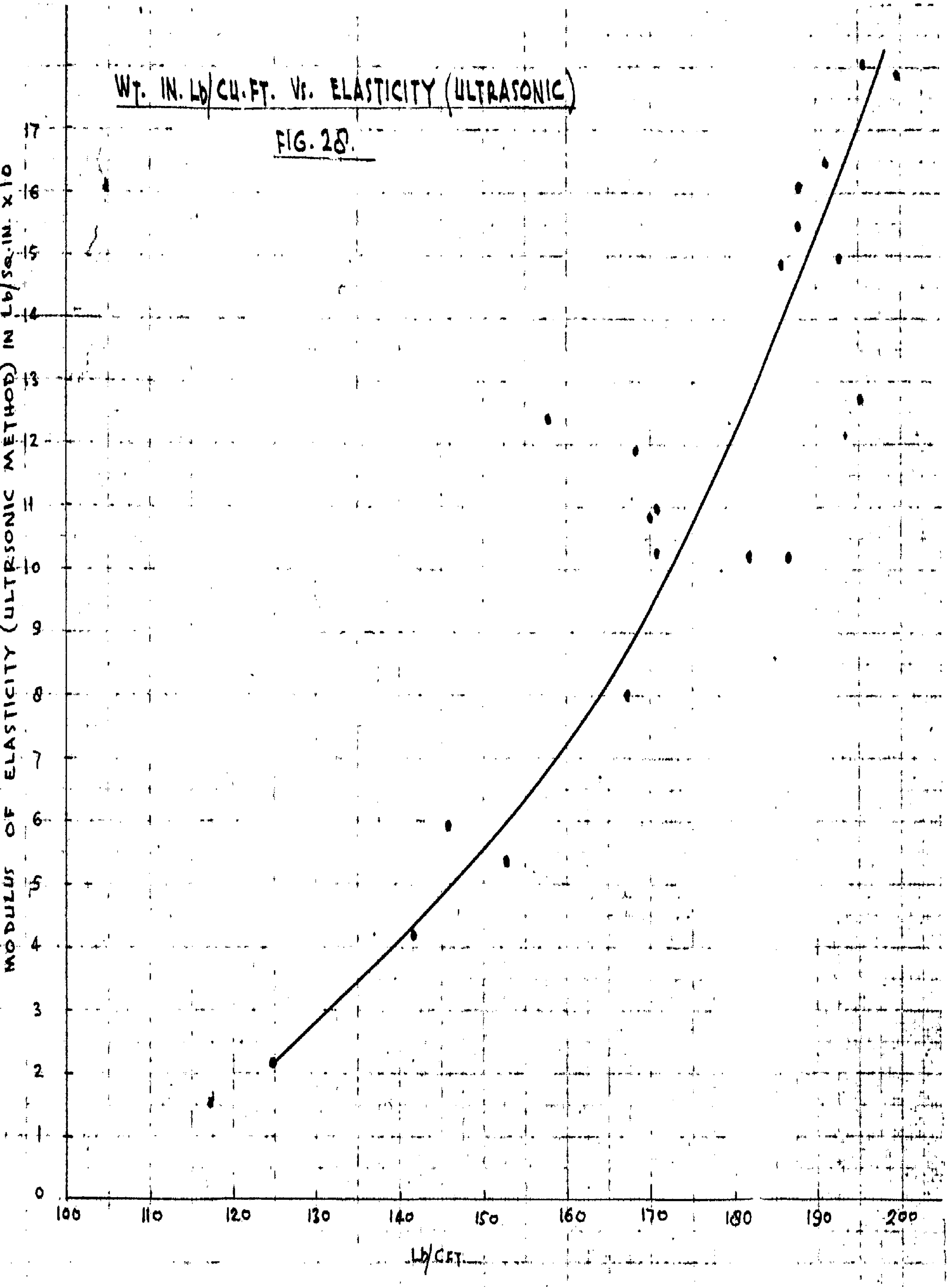
Wt. IN. Lb/CU.FT. Vs. ELASTICITY (ULTRASONIC)

FIG. 28.



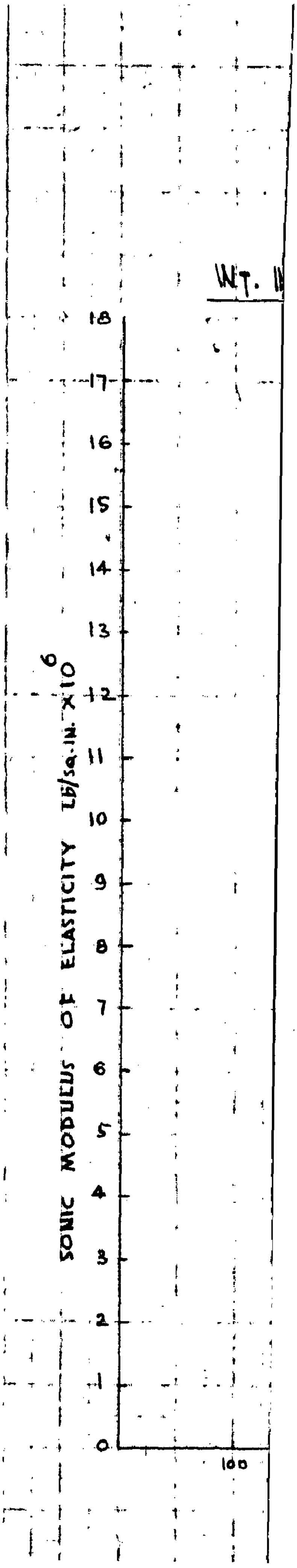
velocities are higher in 'Grain' (Fracture) direction than across it. (See Table No. 76).

The relationship between sonic modulus of elasticity and the wt/cu.ft. is evident from figure 29. The deviation of Granite from Andhra Pradesh (7) is perhaps again due to its hetrogeneous coarse grained texture.

Lastly to draw a comparison between the physical properties with engineering properties a graph showing compressive strengths vs. Elasticity ('ultrasonic) has been plotted (Fig.30) This indicates a close relationship between the two properties except in case of Limestone from Ramganjmandi (4), sandstone from Dholpur (1), Granites from Dodaballabpur and Andhra and Slate from Kurnool. The probable reasons of the exceptional behaviour of the ultrasonic velocities, through those types of rocks has already been explained in connection with the discription of fig. 28 and 29 given above. The deviation of the points in the graphs given in figure 27 to 30, could partly be explained in response to the effects produced by other Physico-chemical properties also, but in order to establish definitely the influence of physico-engineering and petrographic properties a series of tests on the lines carried above would be required and shall form an interesting study.

METHOD PROPOSED FOR THE DETERMINATION OF 'GRAIN' (Cross Fracture or Sculping) in CASE OF SLATES

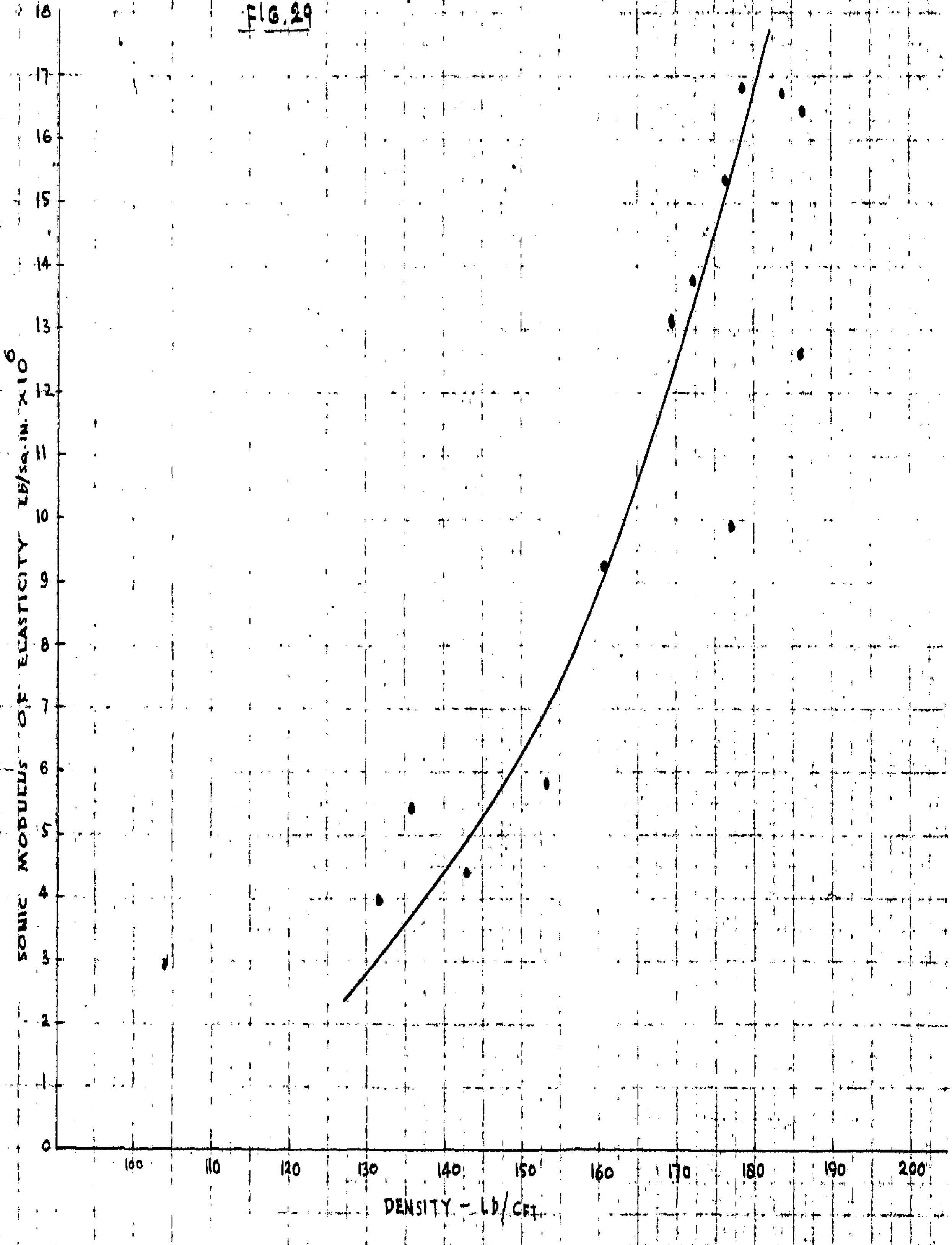
'Grain' (Cross Fracture) is an important property in case of slates for the purpose of quarrying and laying over the



WT. I
SONIC MODULUS OF ELASTICITY LB/SQ.IN. X10^6
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
100

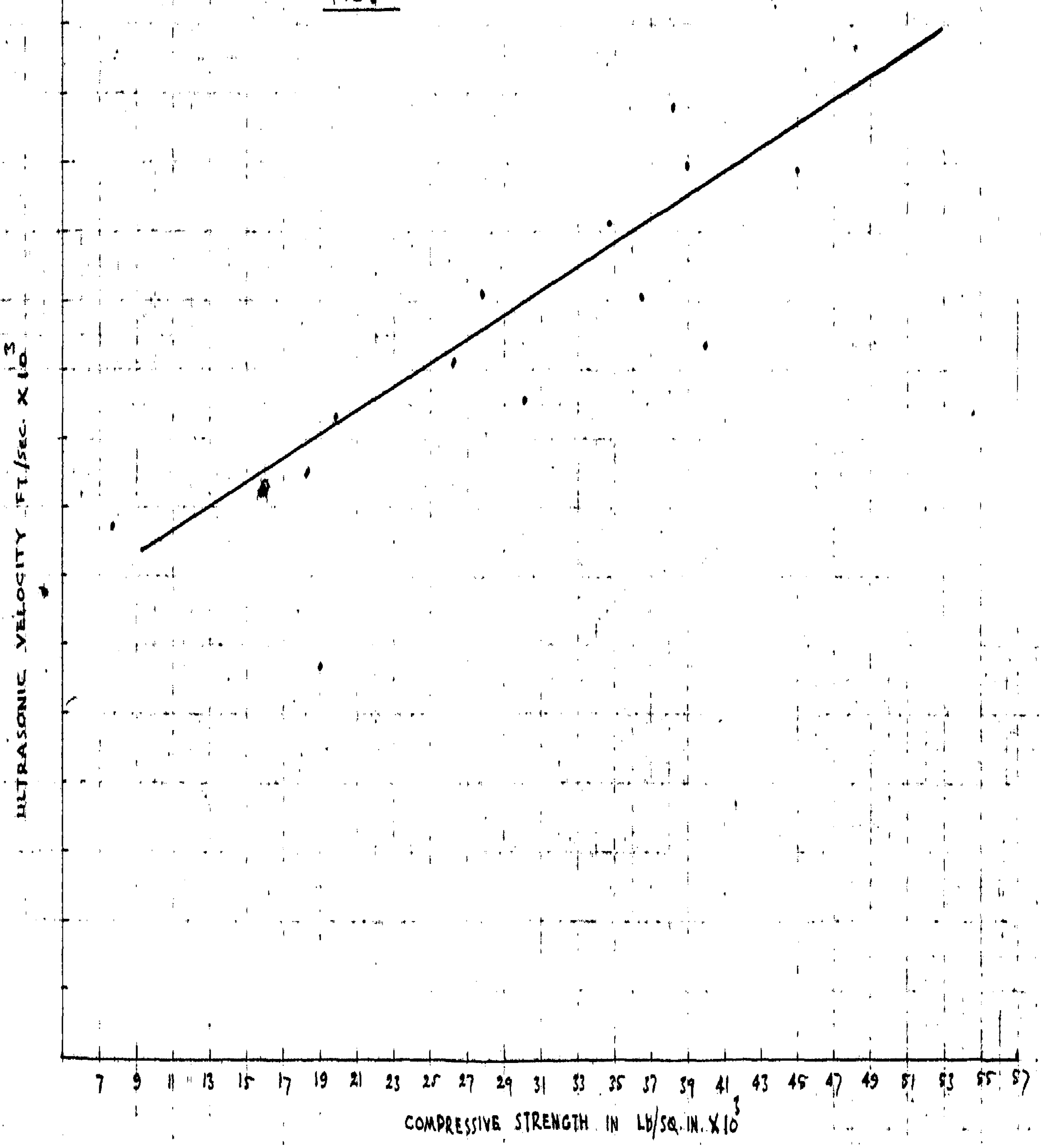
WT. IN LBS/CU. FT. Vs. ELASTICITY (SONIC)

FIG. 29



COMPRESSIVE STRENGTH Vs. ELASTICITY.

FIG. 30



roofs. Determination of the direction of 'Grains' when it is obscurely shown on the cleavage surface becomes a difficult task in slates.

During the ultrasonic test two wave velocities were noted in case of slates as given below in table No. 76.

'Ultrasonic Wave Velocities in Slates'

Rock	Length	Time in M/sec.	Velocity	Remarks
			ft/sec.	
Slate	5"	20.	20,830	Along the 'Grains'
Slate	2"	12.5	13,330	Across the 'Grains'

TABLE No.76.

From the above results it is obvious that the ultrasonic waves travel faster in the Grains direction. Expecting a similar behaviour in case of heat waves travelling along and across the 'Grain' the following test has been devised.

The slate is sawn in a direction parallel to its cleavage and one of the sawn surfaces is made exceedingly smooth. This surface is covered with an even and very thin coat of a mixture of the double iodide of copper and silver in the ratio of 85% and 15% respectively. A pointed flame is then applied to the slate opposite the centre of the coated surface. The heat changes colour of the coated surface from red to almost black and the transition is exceedingly sharp to note the direction along which the changes are more rapid. The media of application for these pigments should be alcohol soluble urea formadehyde resins, shellac or gums.

The direction along which the colour changes are more rapid is the direction of the 'Grain' or 'Cross Fracture' in case of slates.

The test is proposed as a field method since 'Ultrasonic Method' is difficult and cumbersome at the quarries or at building sites.

CHAPTER VIII.

PETROGRAPHY OF INDIAN BUILDING STONES

Building Stones - not only of India, but of any country cover almost all rock types - igneous, sedimentary and metamorphic. Obviously to describe the rock types in detail without having any particular application in view, is an endless effort. In this little space attention has been devoted only to describe a few broad characters to have a better understanding of the internal composition, texture and structure of the Indian Building Stones'. Optical and other details of properties of the constituting minerals have been purposely avoided since they do not appear to have any importance in this study. The classification followed here is according to the Indian Standards[50] Rocks have been described in order of their importance as 'Building Stone'. However, within the groups a chronological order has been maintained as far as possible.

I. SEDIMENTARY ROCKS

Sedimentary formations supply the maximum quantity of stones for building purposes, because of the ease with which these can be quarried, dressed, cut and polished.

SANDSTONES.

A sandstone consists primarily of a framework which is the detrital sand fraction. Voids and pores are the empty spaces in that framework. Hence the study of a sandstone, therefore, centers round on the frame work, its character and make up, nature and volume of voids and void filler. The nature and volume of voids have been studied in Chapter No. V where micro, macro and total porosities have been described along with the pore-structures. The properties of the frame work, its nature and quantitative percentages in proportion to the intragranular detritus are illustrated in figure No. 31. From this it would be clear that all sand-stones used as building materials are mainly composed of quartz grains and the voids are filled intragranular detritus of varying compositions.

Structure and Texture.

Hamamsagar Sandstone (12SST) is a compact well graded sandstone belonging to Kaladgi Series of Cuddapah system of Peninsular India[51]. Most of the sandstones used in buildings are from Shahbad, Dholpur, Kotah, Jodhpur, Bhilwara, Bikaner, Mirzapur and Fatehpur Sikri area (1 SST, 16SST-22SST). They all belong to Kaimur and Bhandar Series of the Upper Vindhyans. Bhandar sandstones are thick bedded and differ considerably from Kaimur sandstones. Wide spread ripple markings and frequent current beddings indicate shallow water deposition. Their fine and uniform grain size helps in easy dressing and carving of the stone (Pl.23 Fig.1). Sandstone from Panchmarhi (9SST) are coarse, white, usually soft sandstone. Beds are seperable from one another by layers of white sub-angular quartz pebbles. Current bedding is common. Sandstones from Orissa near Cuttack (14SST) belong to the Athgarh series of the coastal Upper Gondwanas[52]. Sandstones from Songir, Kutch, Dharangadhra and Ahmadnagar (2 SST, 4 SST, 5 SST and 11 SST) are also fine grained sandstones belonging to the Upper Gondwana age[52]. The outcrops

QUANTITATIVE MINERAL COMPOSITION OF

SAND STONES USED

BUILDING STONES IN

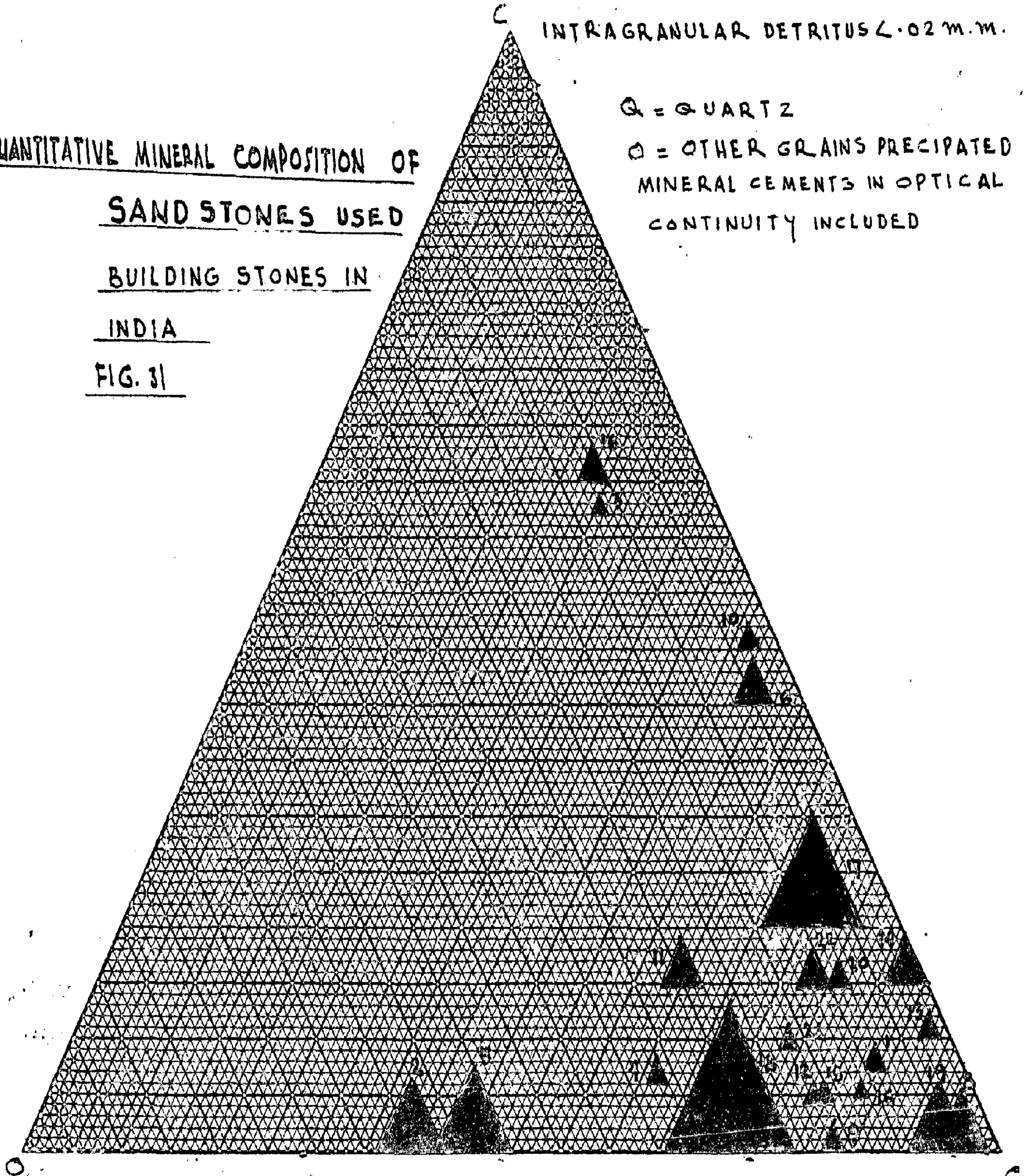
INDIA

FIG. 31

C INTRAGRANULAR DETRITUS < ·02 m.m.

Q = QUARTZ

O = OTHER GRAINS PRECIPATED MINERAL CEMENTS IN OPTICAL CONTINUITY INCLUDED



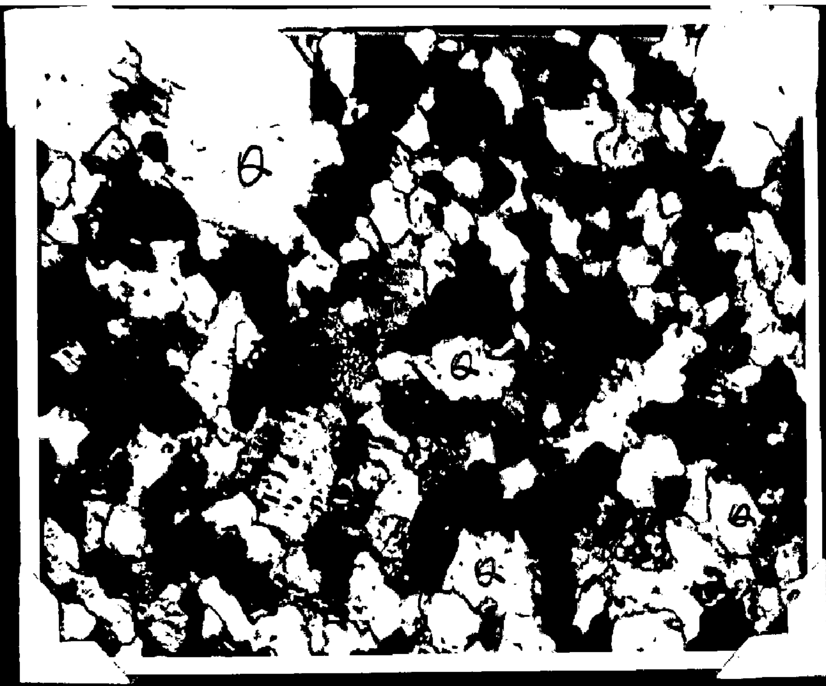


PLATE No.23 Fig.1

PHOTO-MICROGRAPH OF VINDHYAN SANDSTONE SHOWING FINE UNIFORM GRAINS X 60 Q = Quartz Grains.

PDATE No.23 Fig.2

GONDWANA SANDSTONE SHOWING GRAINS OF QUARTZITE.

X 90 = Q = Quartzite Grains

are nearly horizontal and the lower beds comprise of soft yellow sandstones with white specks of Kaolinized felspars and ferruginous concretions. These sandstones are generally white with pinkish markings and streaks. Grains are loosly aggregated. Some samples also show a little percentage of quartzite grains which give the sandstones a conglomeratic appearance (Pl.23, Fig.2), but the more or less rounded grains of quartz always maintain their individuality and the bedding is invariably distinct. Current bedding is common and the beds are traversed by strings and veins of calcite. They vary greatly in texture. Sandstone from Barda Hill (6 SST) which is popularly known as 'Porbander Stone' can be classified sometimes as sandstone and sometimes as limestone depending upon the percentage of silica and lime in the sample. It contains remains of the foraminifers. It is usually sandy or clayey in nature with porous and aolitic structure. Nahan Sandstone (15 SST) is a hard fine grained, grey purplish brown sandstone of Tertiary age.[55]

Mineral Characters.

The great series of Vindhyan Sandstones from Shahbad, Dholpur, Kotah Jodhpur, Bhilwara, Bikaner, Mirzapur and Fatehpur Sikri area include sandstones with 70% to 90% or even more of well rounded and excellontly sorted quartz grains (Pl.24 Fig.1). Sandstones from Shahbad, Dholpur, Kotah, Jodhpur, Bhilwara and Bikaner (1 SST, 16-20 SST) belonging to the Upper Bhander Series are less metamorphosed as compared to those belonging to the Kaimur series i.e. from Mirzapur and Fatehpur Sikri Area (21 SST, 22 SST). In Kaimur Sandstones the sand grains are nearly all beautifully rounded and coated with a cement of secondary silica. Tourmaline is sometimes seen. Felspars are absent. Under the microscope, the boundaries between the overgrowths of secondary silica and the original detrital cores are usually well displayed by thin "dust rings" (Pl.24 Fig.2).

In the case of sandstones of Upper Gondwana from Dharangdhara, Athgarh, Ahmadnagar and Kutch etc. as described above, quartz particles are present with Kaolinized felspars in varying amounts. Pinkish markings and streaks of limonite with occasional ferruginous concretions are invariably present. In certain cases, such as Panchmarhi Sandstones (9SST) some angular quartz grains are also seen under the microscope while the very coarse varieties show some grains which are made of quartzites.

Mineral Character of Cementing Matrix.

The Upper Bhandar Sandstones are generally characterized by the deep red colour with spots or speeks of white tints. Sometimes bands of red and white colour are beautifully arranged. The colour source is invariably iron oxide and as such these can be called ferruginous sandstones (Pl.25 Fig.1). The white spots and bands alternating in these red sandstones which are very popular in Delhi are reported[53] due to the bleaching action of carbonated waters. Kaimur Sandstones are greysh, yellowish or pinkish and sometimes speckled with brown or brownish purple patches. In this case the cementing matrix is silica clay (Pl.25. Fig.2). Colour is due to the various oxides of iron staining secondary minerals in the matrix. Dendrites of manganese oxide are seen in both cases.

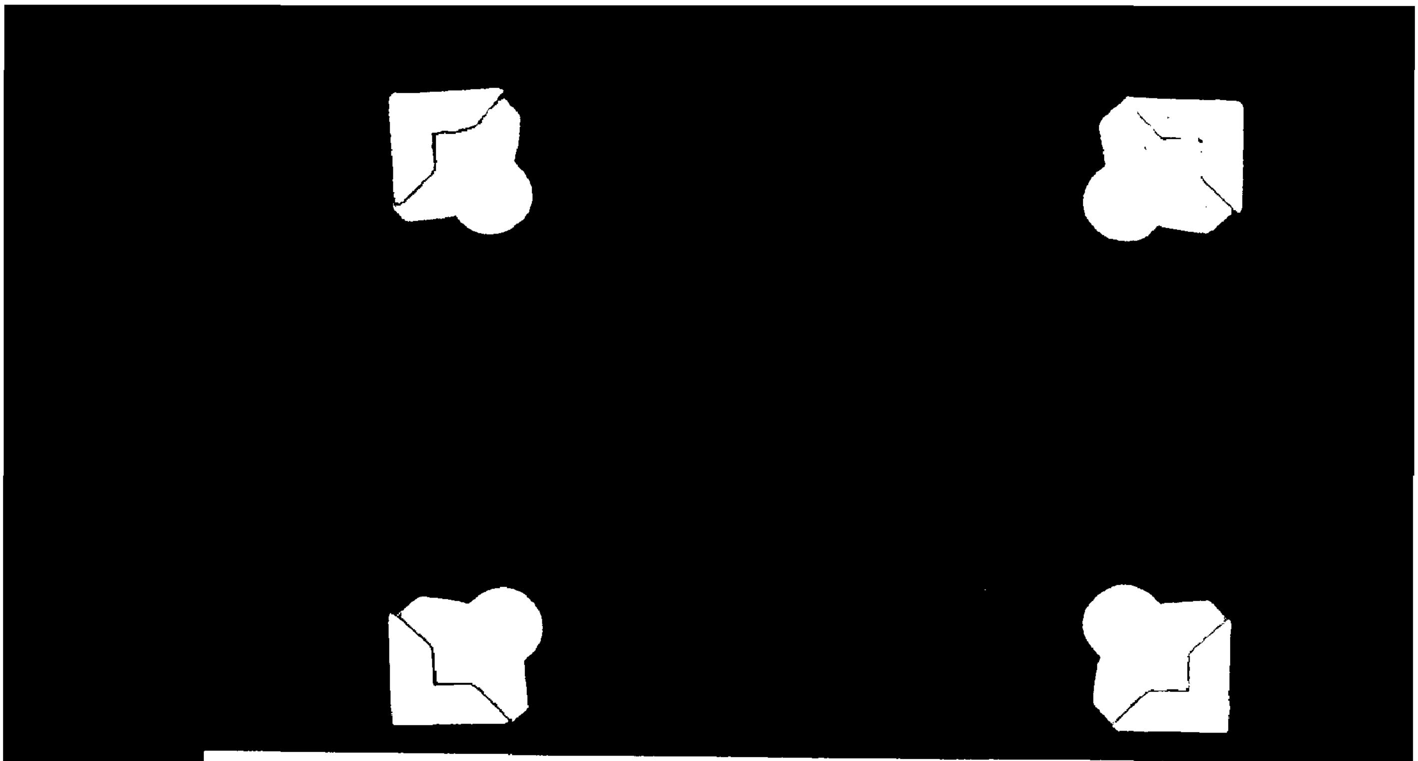


PLATE No.24 Fig.1

PHOTOMICROGRAPH OF DHOLPUR SANDSTONES SHOWING WELL ROUNDED AND EXCELLENTLY SORTED QUARTZ GRAINS

X 65 Q = Quartz Grains & I. = Infragaanular Delritus.

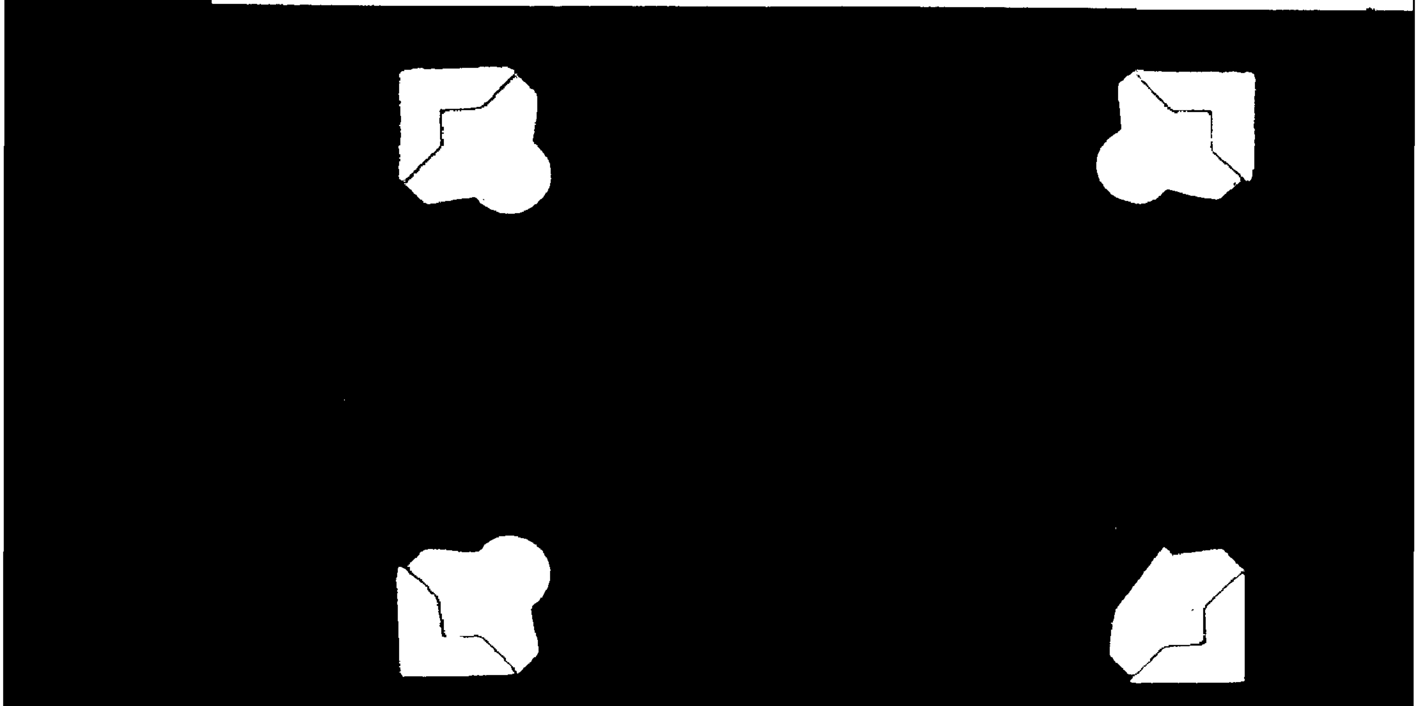


PLATE No.24 Fig.2

PHOTOMICROGRAPH OF SANDSTONE WITH AUTHIGENIC OVER-GROWTH OF SECONDARY SILICA ON THE PRIMARY DETRITAL QUARTZ GRAINS. O = Overgrowth of Silica x 45

The Upper Gondwana sandstones the cementing material isamixture of silica and iron. Small veins of calcite are sometimes seen. Clay also forms an appreciable amount of the void filler. In case of Nahan Sandstone silica and some clay matter forms the cementing material. 'Porbander Stone' (6SST) is a calcareous sandstone composed largely of foraminiferal shells and some clayey and sandy material.

The relative proportion of cementing material to grains can be judged by Fig. 31.

LIME-STONES.

Limestones rank next to Sandstones in use for building purposes. These are especially employed for flooring and facing purposes. Generally there is a wide difference in texture and structure of the limestones and the variations are easily identified in hand specimen. Occasionally the variations can only be brought out under the microscope. After the studies of physical, chemical and engineering properties, it has been observed that in the case of limestones petrographic examination in general does not yield enough additional information to justify a detailed examination.

The fabric of all the Vindhyan Limestones has been briefly studied. They show an anisotropic crystallographic fabric. In some sections only a randomly scattered distribution of calcite and dolomite crystals has been observed with dimensional (rather than crystallographic) fabric like other mechanically deposited materials.

PLATE No.28 Fig.1

PHOTOMICROGRAPH OF FERRUGINOUS SANDSTONE (BHANDER)
x 40

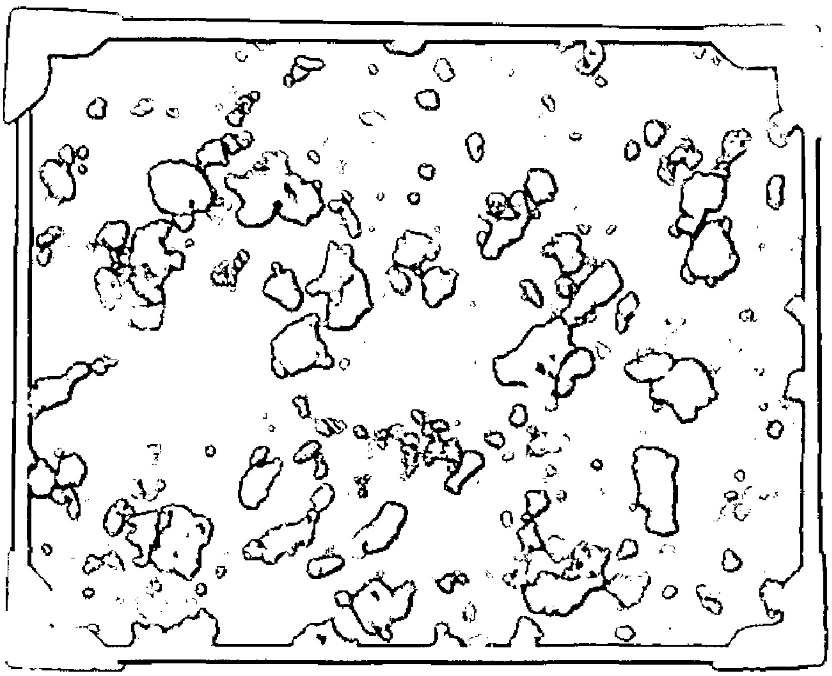


PLATE No.28 Fig.2

PHOTOMICROGRAPH OF KAIMUR SANDSTONE WITH
SILICA CEMENT x 60.

In limestones colour ranges from pure white to black and any kind of shade can be expected within them. The variations in colour are due to the character and amount of impurities present. The principal colouring agents are organic matter and iron oxide.

Kaladagi limestone (7 Lm.St) occurs in varieties of pink, purple, green, grey and black and belongs to the Kaladgi series of the Cuddapah system. Khandara limestone (6 Lm.St) is composed of well bedded limestone of fine grains but occasional secondary silica particles are observed. It varies in shades of grey or buff colours, but is seldom red. It belongs to Penganga beds of the Cuddapah System.[52]

The famous 'Cuddapah Slabs' (2 LMST) belongs to the Narji Stage of Jammalmaduju Series of Vindhyans.[52] They are calcareous slates, deep red, green, black, grey and white in colour. These are extremely fine grained, and compact. The non-compact crystalline variety is somewhat siliceous in composition. The grey variety which is crystalline and compact weathers with surfaces resembling certain corals. Near Kurnool, it rests on gneisses and becomes cherty and brecciated.

"Shahbad Slabs" (3 Lm.St) are found generally as flaggy limestone. The rock is for the most part fine grained and has a texture approaching that of lithographic stone. Grey is the prevailing colour but drab and pink tints are common.

Katni (5 Lm.St.) is a fine grained unfossiliferous limestone of Vindhyan system. Ramganjmandi Limestone (9 Lm.St) occurs as flag stone in thin seams extending over a large area south of Mukandwara upto Au River in Rajasthan. It belongs to Nimbahera stage[54] of the Semri Series. The Chittor limestone (10 Lm.St) is a fine grained, non-crystalline, generally hard, smooth, compact variety and the layers are generally only a foot or too thick. It can be obtained in all shades of grey, greyish green, pale bluish with occasional layers of brown, pink and chocolate brown.

Jaisalmer limestone (11 Lm.St) is a yellow, fine and uniformly textured Jurassic Limestones. An ornamental stone from Abur (27°05': 70°37') is a dark red fossiliferous limestone with yellow shells. It consists of thick buff coloured, inter-stratified bands of siliceous varieties with platy form of grains. (Pl. 26, Fig.1). In trade it is called as 'Marble'.

Pindara limestone (4Lm.St) is a fine grained fossiliferous limestone of orange yellow colour which become red on exposure to weather.

Khasi Hills Limestone (1 Lm.St.) popularly known as 'Sylhet Limestone' belongs to the Sylhet limestone stage of Eocene age[55]. These are fossiliferous limestones with nummulities and are often of very high purity and quality.

LATERITES

Petrographically the subject of Laterite is of much controversial nature. Depending upon their probable mode of origin the laterites have been classfied as 'Primary (formed in situ) and secondary (detrital and reconsolidated)[56]. The primary laterite

PLATE No.26 Fig.1

SURFACE PHOTOGRAPH OF JURASSIC LIMESTONE WITH YELLOW SHELLS (NATURAL SIZE)

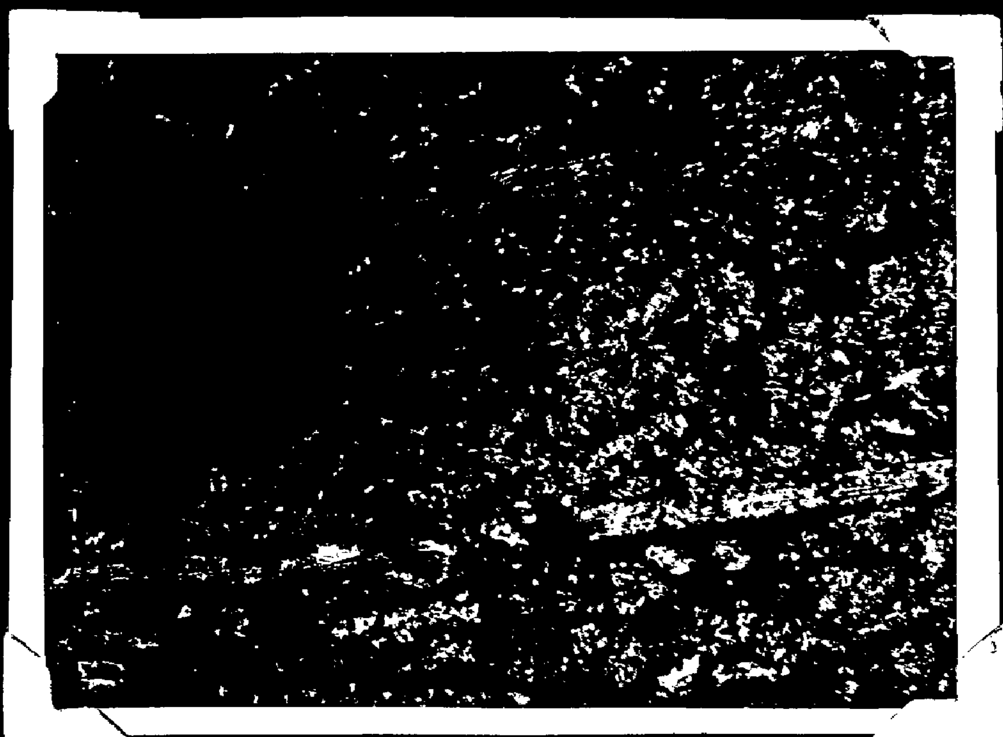


PLATE No.26 Fig.2

PHOTOMICROGRAPH OF PINDARA LIMESTONE x 60 is a residual weathering product of various types of igneous, sedimentary and metamorphic rocks.

Laterites from Pattukkottai (1 LT) and Bhandara (2 LT) belong to Primary class where as those from Belgaum (3LT) and coastal districts of Orissa are classified as "Secondary".[56]

Perhaps the most obvious fact about any type of laterite is its porous nature. Primary laterites (1LT and 2 LT) are pisolitic in nature (Pl 27. Fig.1). The tortuous tubes are quite irregular and have no directional arrangement (Pl.27 Fi.g2). Sometimes they are vertical and occasionally horizontal. The matrix of the mass is generally ferruginous, and the tubes are lined with a limonitic glaze and filled with cream coloured, powdery, aluminous laterite or lithomarge. The surface is always irregular rough and frequency of scoriaceous aspect. In the detrital varieties from Belgaum and Orissa (3LT and 4 LT), it is often possible to distinguish grains of quartz embedded in the rock.

The microstructure and textures of amorphous parts of laterite are exceedingly complicated. It appears they have some fine grained cellular and micro-crystalline structure.

The microscopic examination of thin sections of 'Laterites' has failed to reveal any transparent crystalline mineral other than gibbsite. The constituents of laterite are possibly in the form of colloid gels with variable H_2O content (see next chapter No. IX).

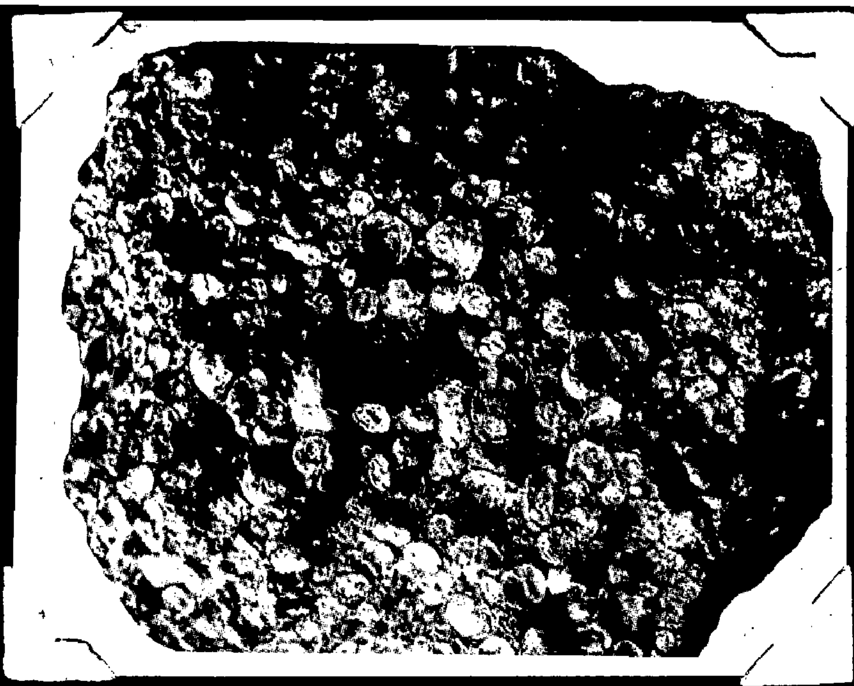


PLATE No.27 Fig.1

SURFACE PHOTOGRAPH, LATERITE SHOWING PISOLITIC STRUCTURE

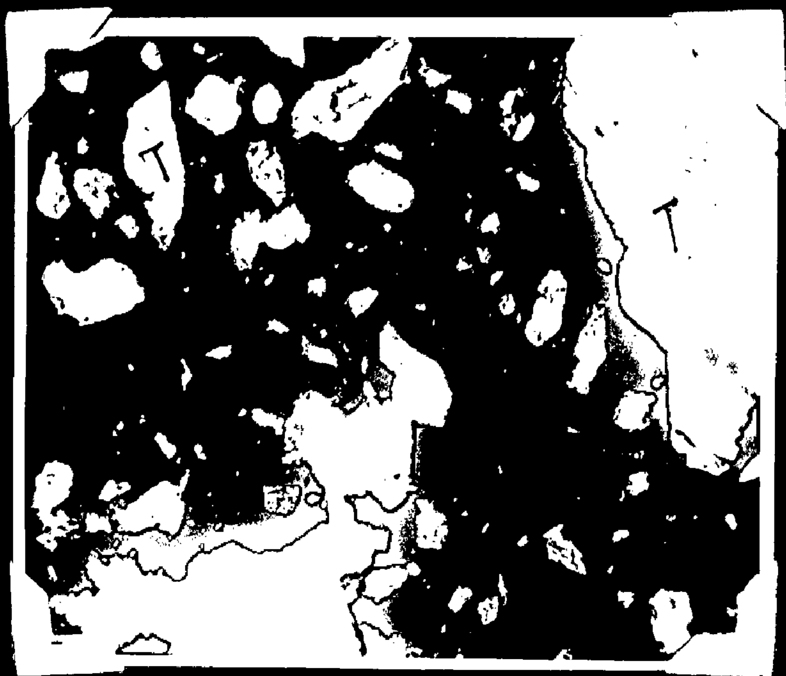


PLATE No.27 Fig.2

PHOTOMICROGRAPH OF SHOWING LATERITE TUBES ARRANGED IRREGULARLY AND HAVING NO DIRECTIONAL ARRANGEMENT

T = Tubes.

II. IGNEOUS ROCKS

Igneous rocks are used as 'Building Stones' mainly in South India, where they are exposed in abundance. Their use is more popular because of the non availability of good quality sandstone deposits.

Except for the traps, they all belong to Archean System.

Granites

The word 'Granites' as commonly used in the stones are composed of mainly quartz and felspar with usually some mica, occasionally hornblende and rarely augite. The technical properties of granites as considered important from the commercial point of view, are diffeerence in colour, structure, texture, fabric, xx coarseness of grain and mineral constituents.

Colour

The colour of granites is determined largely by the colour of the predominent mineral which in most cases is felspar and in few cases by the occurence of dark minerals like biotite, hornblende and augite. Most of the commercial granites available in India are quite rich in colour combinations. The usual shades are white, mottled white, light grey, grey, dark grey, black, pink and reddish.

Structure

The grain size is very variable. The rocks are some-times giant grained, very coarse grained, medium grained and fine grained (Pl.28 Fig. 1&2). Most of the individual constituents in all these granites from Hyderabad, Guntur, Bhulvan, Orissa, Bangalore and Sambalpur (1GR-6GR) can be distinguished megascopically. These

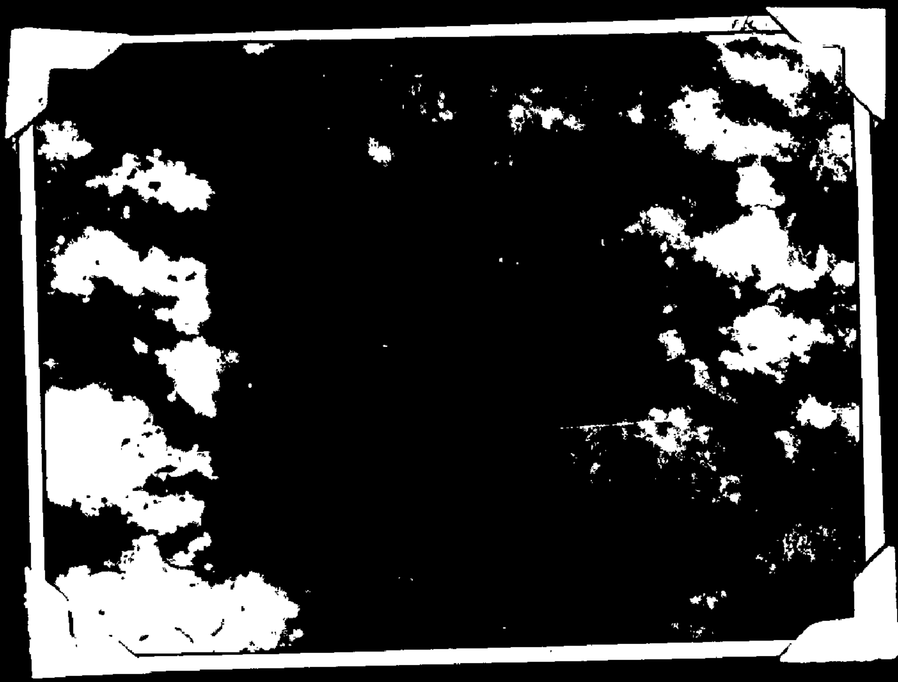


PLATE No.28 Fig.1

SURFACE-PHOTOGRAPH SHOWING COARSE GRAINED GRANITE FROM DODBALLABPUR (Natural Size)

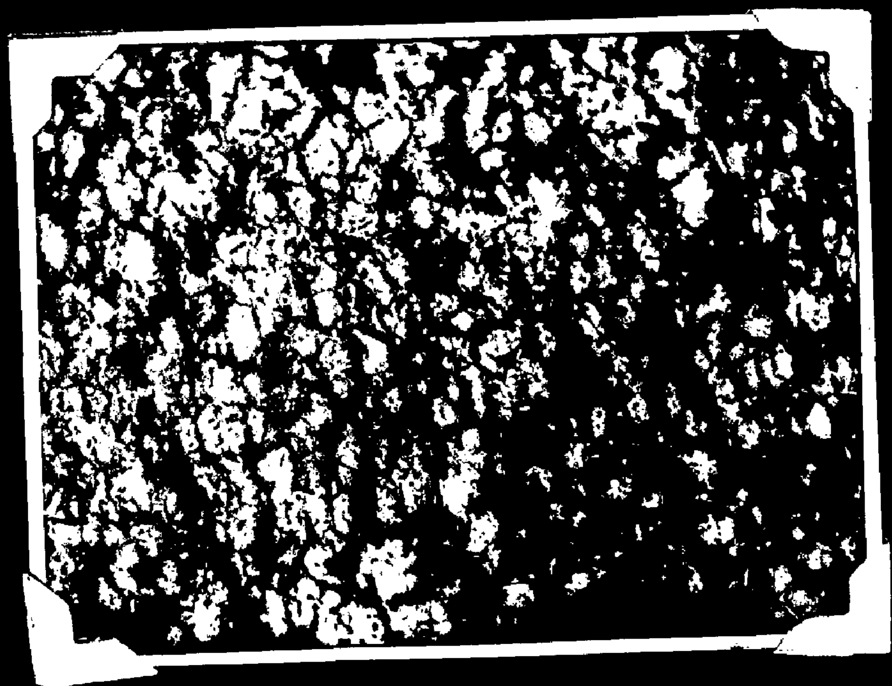


PLATE No.28 Fig.2

SURFACE PHOTOGRAPH SHOWING FINE GRAINED GRANITE FROM HYDERABAD x 3/4 (Natural Size)

Granites show no trace of lamination or gneissic structure and are massive in nature. Master joints which are generally parallel to the surface are commonly met (Pl.29). These joints break the granites into flat lenses. Sambalpur Granite (6GR) exhibited an obscure rift.

Texture

From the Ultrasonic and Sonic studies it appears that in case of Granites rock textures play an important role in the determination of their physical, engineering and elastic properties.

Granites from Hyderabad West Taluka (1GR) and Guntur (2GR) are holocrystalline, granular and phanero-crystalline in nature (Pl.30 Fig.1)

Granite from Bulvan (3GR) is hypautomorphic granular in texture.

Granites from Madura (4GR) and Bangalore (5GR) vary in texture and are uniform or coarsely porphyritic in nature (Pl.30 Fig.2). These variations in grain size sometimes give an appearance similar to the Peninsular gneiss.

Sambalpure Granites (6GR) are coarse porphyritic in nature with phenocrysts of felspar chiefly orthoclase generally automorphic and twinned. Foliation is rare.

MINERAL CONSTITUENTS

Felspars - The characteristic felspar of all the granites is orthoclase. On fresh fractures it has a pearly lusture and is usually reddish, pinkish or yellowish white in colour. Crystals are mostly tabular and the crystal boundaries except against quartz are perfect. Twinning on carlsbad law is quite common (Pl.31 Fig.1)

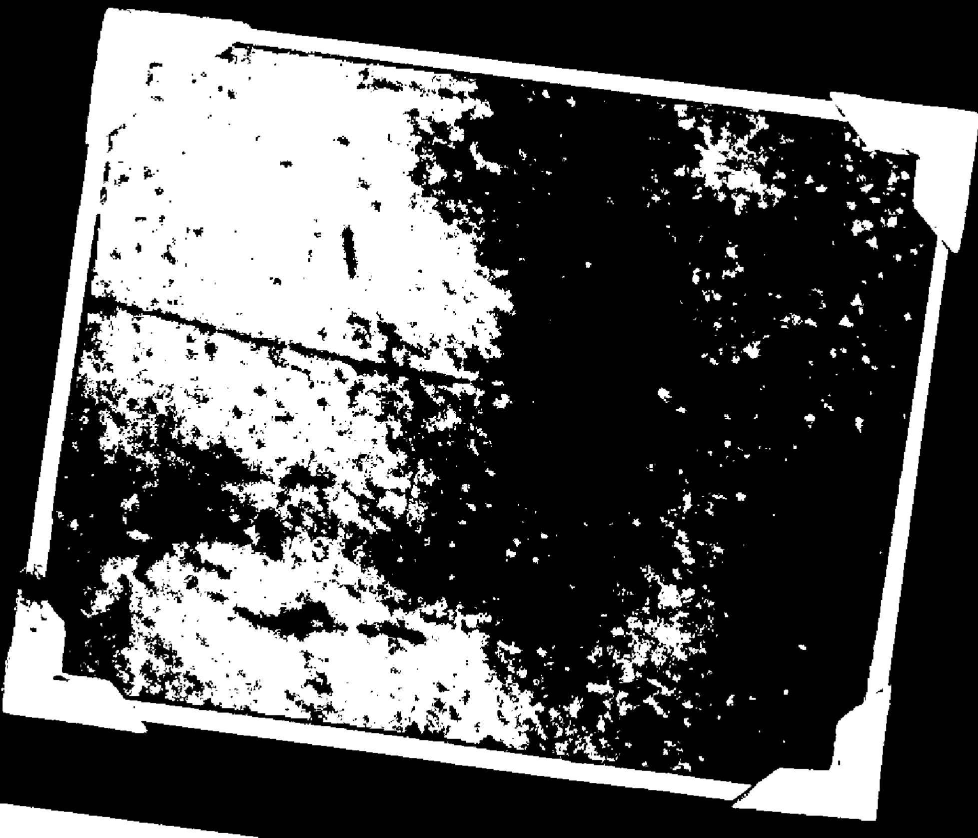


PLATE No.29

MASTER JOINTS IN GRANITE (HYDERABAD)

Quartz - Megascopically as well as under the microscope quartz is invariably present in all the granites studied here. It is colourless and fills interestices between other constituents of the rock. In case of Granite from Bangalore the larger quartz grains exhibit a strain shadow, sweeping across the crystal (Pl.31 Fig.2). Quartz in Guntur Granite (2GR) is crushed into a sort of mosaic giving a mortar texture. Inclusions in quartz are quite common.

Biotite - Amongst the ferromagnesion minerals, biotite is most common and varies from a few percent to about 25%. Under incident light the biotites are black or brown in colour and by transmitted light they look brown or green. In the thin basal sections cleavage is not seen but when at right angles to this direction, perfectly well developed (001) cleavages are seen. Pleochroism is marked.

Muscovite - Next to biotite, muscovite also occurs in these granites, but is never very abundant. It is colourless in thin sections.

Hornblende - Under microscope brownish green hornblende is found in Granites from Hyderabad, Bangalore and Sambalpur. The crystals are usually prismatic. Cleavage lines (110): (110) intersecting at 56° approx. are commonly seen.

Accessory minerals - Magnetite, apatite, and zircon are present as minor accessories.

Alterations - Orthoclase is often Kaolinized. Both Kaoline and Sericite are frequently arranged either along borders or along

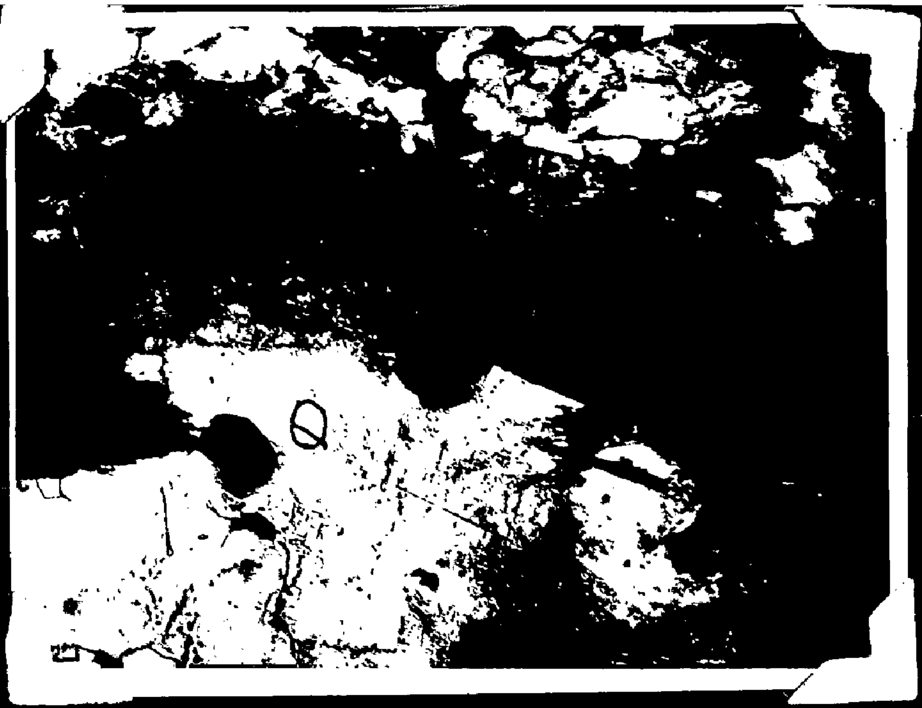


PLATE No.30 Fig.1

PHOTOMICROGRAPH OF GRANITE FROM GUNTUR X 80
Q = Quartz, F = Felspar.

PLATE No.30 Fig.2

PHOTOMICROGRAPH OF GRANITE FROM BANGALORE SHOWING COARSE PORPHYRITIC VARIETY x 60.

cleavages. Sometimes all the crystals are cloudy. In case of Bhulvan and Madura granites chlorite is seen perhaps as an alteration product of hornblende.

BASALTS (Amreli & Nagpur)

Basalts are described here on the basis of their composition. They all belong to Deccan Traps.

Except for minor differences the trap rocks of the basic type are generally dark grey to black in colour and exhibit a uniform character. Under thin section the textures of the rocks are porphyritic with phenocrysts of plagioclase set in an aphanatic groundness (Pl.32 Fig.1) The matrix is mainly composed of plagioclase felspars, monoclinic pyroxene, opaque ores and glassy base in varying amounts. Olivine is represented by its pseudomorphs occuring sparingly.

The phenocrysts of plagioclase felspars are more or less zoned but within the labrodorite range (Ab_{40} An_{60-65}%). These felspars also occur in ground mass as minute laths upto 1 mm. long and are characterized by usual poly-synthetic twinning.

Next to plagioclase, monoclinic pyroxenes rank in abundance as an essential constituent of these rocks. They are mostly confined to the ground mass, but a few irregularly bounded microphenocrysts are found occasionally. The prismatic cleavages are well developed.

Titaniferous magnetite in the form of plates and grains, some glass and pseudomorphs after olivine occur as accessory constituents. Ilmenite is usually present.

PLATE No.31 Fig.1

PHOTOMICROGRAPH OF FELSPAR IN GRANITE FROM HYDERABAD
X 120 T = TWINNING ON CARLSBAD LAW.

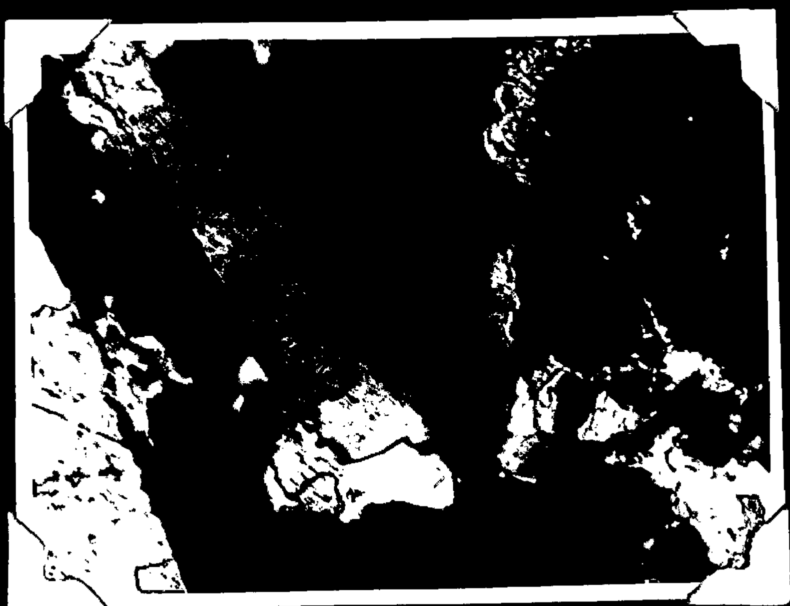


PLATE No:31 Fig.2

PHOTOMICROGRAPH OF GRANITE FROM BANGALORE SHOWING
QUARTZ (Q) EXHIBITING SRAIN SHADOW.

A tendency to ophitic texture is visible with coarse textures in rocks of the Nagpur area (Pl.32 Fig.2) In grain size the crystalline portion of the ground mass varies from micro-crystalline to microlitic. The pyroxene grains are generally inserted into the plagioclase laths but in places the latter tend to penetrate the pyroxene grains. Felspars are often Kaolinized and the pyroxene is chloritized.

Acid Traps (Baroda)

It is a light cream coloured fine grained rock. The ground mass is largely fine grained and contains a few big crystals of quartz and felspar. Felspars include both the orthoclase and oligioclase measuring upto 8x3 mm. Lamellar twinning is also present. Subordinate crystals of quartz and apatite are seen. Pyrite is present in good amount. Ferro-magnesian minerals are not seen. Structural appearance is granophyric but occasionally arrangement of phenocrysts indicate a flow structure. Texture is fine-grained, holocrystalline.

Trachytic Traps (Bardari Hill and Kurla Trap)

These are light buff and cream coloured rocks with a fine flow structure. Porphyritic character is also prominent though the phenocrysts are small and do not measure more than 8x3 mm. As compared to the Acidic Traps, these rocks contain less quartz and no granophyric material. In thin sections the phenocrysts of acid oligoclase or nearby pure albite exhibiting characteristic multiple twinning is commonly seen. The rocks are mainly composed of aphanatic felspathic material. Acid plagioclase make up the ground-mass of the rocks. It frequently contains some

PLATE No.32 Fig.1

PHOTOMICROGRAPH OF BASALT (AMRELI) SHOWING PHENOCRYSTS (P) OF PLAGIOCLASE SET IN AN APHANATIC FINE GROUNDMASS (A) X 120.

PLATE No.32 Fig.2

PHOTOMICROGRAPH OF BASALT (NAGPUR) WITH A TENDENCY TO OPHITIC TEXTURE X 250 F = Felspar, A = Augite.

calcite and pyrite. Palagonite fibres having straight extinction and a moderate birefringence are seen, perhaps as an alteration product. Apatite and opaque minerals are also present as accessories (Pl.33 Fig.1).

DOLERITE (Dodballabpur)

This is a dark coloured rock similar to the basalts described above. It differs in being more coarse grained and non amygdaloidal or vesicular. Its mineral composition is the same as those of basalts. It is holocrystalline with ophitic texture (Pl.33 Fig.2).

DIORITES (Mandya and Srirangpatna)

Diorite from Mandya district (1Di) is porphyritic in nature with hornblende and phenocrysts of dull grey felspar embedded in a chocolate coloured matrix with epidote. Texture is holocrystalline. The plagioclase felspars are oligoclase and andesine exhibiting polysynthetic twinning on the albite law. Under the microscope they appear as broad laths. Hornblende is greenish in colour and basal sections show typical hexagonal forms with angles of approximately 60° and 120° between cleavages. Apatite and zircon occur as inclusions. Quartz occurs only as an accessory mineral besides other minor accessories like magnetite and ilmenite, along with secondary mica, epidote, zoisite, calcite and chlorite in minor percentages. Matrix being light pink, Diorite from Srirangapatna (2Di) is a light pink coloured rock. Other characters are almost the same as in the case of Mandya Diorite.

PLATE No.33 Fig.1

PHOTOMICROGRAPH OF TRACHYTIC TRAP SHOWING SANIDINE PHENOCRYSTS. (S = SANIDINE).

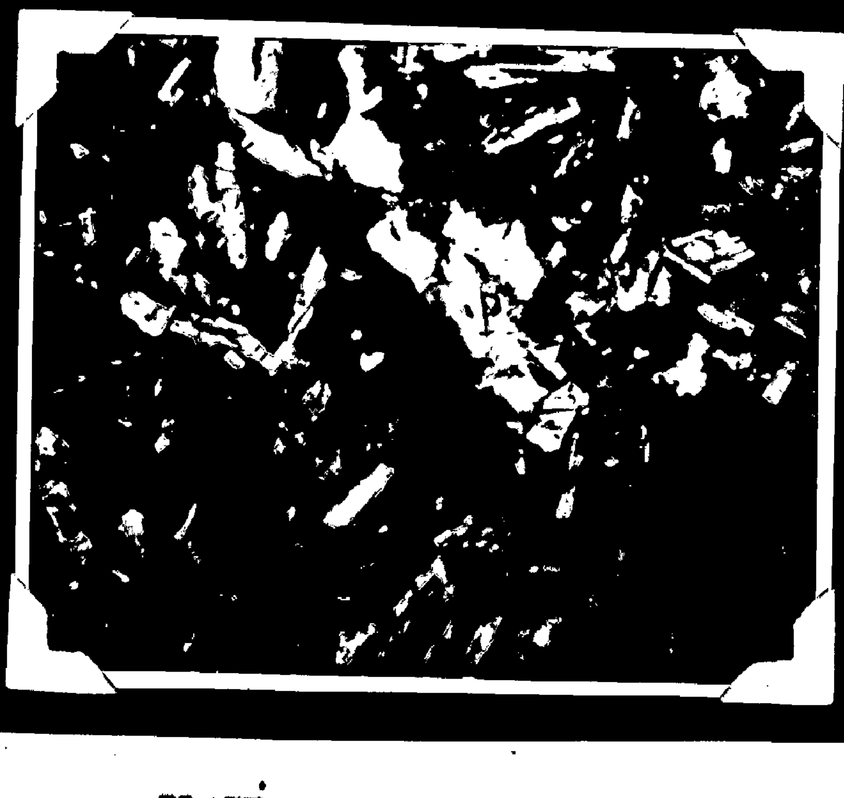


PLATE No.33 Fig.2

PHOTOMICROGRAPHS OF DOLERITE FROM DODBALLABPUR SHOWING PLAGIOCLASE FELSPAR CRYSTALS (P) IN A FINE GRAINED MASS.

NORITE

It is a dark coloured rock of Xenomorphic granular texture. The chief minerals are the basic plagioclase felspars and the orthorhombic pyroxene. The usual pale green pleochroic augite is associated with hypersthene in this rock. Greenish brown, highly pleochroic hornblende is extremely common. Biotite, hornblende, olivine, magnetite and quartz are present as accessories (Pl.34 Fig.1)

GABBRO (Maddur, IGB)

It is a dark coloured more or less coarse grained rock. Under microscope it is holocrystalline, granular in texture.

The felspars are mostly labrodorite. Polysynthetic twinning after albite law is common. Inclusions are present in the form of ilmenite and rutile. Felspars are often kaolinized. Brownish augite occurs in short, tabular stout prisms. The extinction angle is high and variable giving rise to zonal banding. Hour-glass structure is also seen. Biotite is present as an accessory in the form of irregular flakes. Other accessories are titaniferous magnetite, limenite, tourmaline, corundum, apatite, and zoisite (Pl.34 Fig.2)

SYENITE (Kodiyala, Isy.)

It is a medium grained light grey coloured rock consisting of the minerals orthoclase, acid plagioclase, felspathoids and some ferro-magnesian minerals. In texture and many other properties it is similar to granites described above. Quartz is present only as an accessory in some varities. Dark minerals are mainly biotite and hornblende.

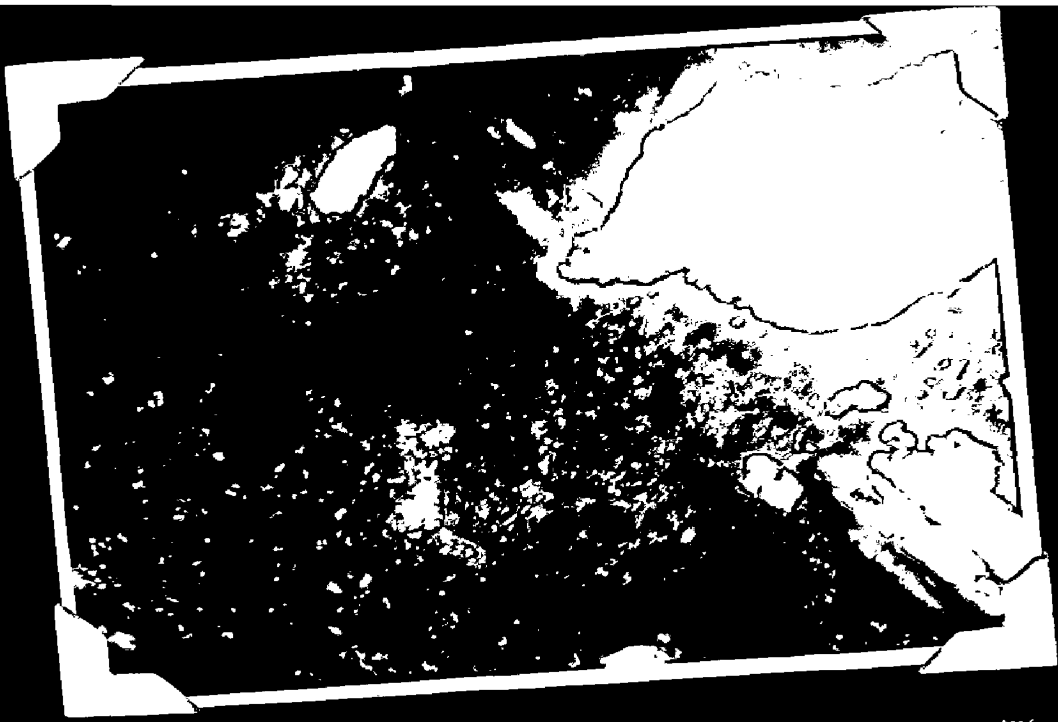


PLATE No.34 Fig.1

PHOTOMICROGRAPH OF NORITE

PLATE No.34 Fig.2.

PHOTOMICROGRAPH OF GRABBRO (MADDUR)

CHARNOCKITE (Andhra 1 CH)

They comprise a whole series of rocks ranging in composition from acid to ultrabasic, the intermediate (Syeno-dioritic) type being the most common. The acid type was called 'Charnockite' by Sir Thomas H. Holland after job Charnock, the founder of Calcutta, whose tombstone is made of this rock. Later the name was extended to cover the whole series[57]. Charnockites are fairly distributed in Peninsular India.

The rock is bluish grey in colour, compact, massive with holocrystalline and granitoid in texture. The colour is imparted by the waxy looking bluish grey quartz. The presence of orthorhombic pyroxene (hypersthene) is an important feature. Augite, hornblende and hypersthene are the chief ferromagnesian minerals. Hypersthene shows marked pleochroism. Augite is titaniferous. Garnet, zircon, magnetite and ilmenite are present as accessories (Fig. 35, Fig.2).

III. METAMORPHIC ROCKS

MARBLES AND CRYSTALLINE LIMESTONES

Stones which are grouped as Marbles and Crystalline limestones are made up entirely of tightly knit grains of calcite rarely dolomite. The crystalline character of these component grains is obvious even without the use of microscope. Hence as in the case of limestones thin section study of these rocks serve a very little useful purpose.

PLATE No.35 Fig.1

PHOTOMICROGRAPH OF SYENITE (KODIYALA) SHOWING ORTHOCLASE FELSPAR X 60 (O = ORTHOCLASE FELSPAR)

PLATE No.35 Fig.2

PHOTOMICROGRAPH OF CHARNOCKITE FROM ANDHRA (H = Hypersthene) x 60.

In texture the marbles vary from coarse to fine in grain and the white varieties are typically saccroidal in nature. Grains are generally between 2 mm. to 5 mm. in diameter in case of Motipur and Devimata marbles. Bands of various colours and shades are common (Pl.36 Fig. 1&2). Baroda marbles are of ophicalcite type. Mostly the texture is granoblastic. Grains show twinning, striae parallel to crystals.

For general use the fine grained varieties are preferred in Indian trade. Marbles are available in any shade extending from fine milky white to black in colour. The dark streaks in some white marbles of Makrana and especially that of Narnaul are due to the local bands of graphitic or organic matter present in the original limestone. Occasionally diopside is seen with calc. silicates. Pink colour is perhaps due to the limonite present in the original limestone. The value of the marble depends upon various surface textures and colour combinations.

Limestones from Yellandu (1 CL) and Bettadabedu (2CL) are crystalline limestones of Archean age. Marble from Makrana (2MB) Devimata (3MB) and Narnaul (4MB) belong to Railo Series of the Archean system[52].

SLATES

Slates are the result of dynamic metamorphism of ordinary argillaceous sediments. The fissile character is well developed in all Indian slates except the one from Cumbum (1SL). The commercial value of these slates depends primarily on the existence of the well developed planes of splitting (Pl.37 Fig.1) Petrographically there is not much to be seen in case of slates.

PLATE No.36 Fig.1

SURFACE PHOTOGRAPH OF MARBLE SHOWING VARIOUS COLOURED BANDS (PEPSU MARBLE) 1/2 Natural Size
NARNAUL

PLATE No.36 Fig.2

SURFACE PHOTOGRAPH OF MARBLE SHOWING PATTERNS (BARODA MARBLE)

The colour of the slates is perhaps due to the presence of organic matter and the iron oxide. In all probabilities they contain a good amount of finally devided carbonaceous matter and iron in the ferrous form.

Slates from Kharakpur Hill (3SL), Surajpur (4SL) and Dharamshala (5SL) are generally red or purple in colour. This colour in slate may be due to the feric form of iron. Slate from Dharamshala is not a superior type and the cleavages, though well developed, are not regular. Kund Slates (6SL) are the best varieties available in Northern India. They are sonorous and are dark in colour. The dark colour after years of exposure develope uneven patches of rust colour. This is perhaps due to oxidization of ferrous form of iron into ferric form. Slates from Kharakpur and Dharamshala are clayey in nature.

QUARTZITES

Quartzites from Alwar (1Qzt) Jhiri (3Qzt) and Delhi (4Qzt) belong to Alwar Series of Cuddapah system[52]. They are pale in colour, though more or less streaked and mottled with brown and red tints according to the amount of iron oxide coating over the grains. They are vitreous in nature and break with sub-conchoidal fracture and sharp splintery edges. In thin sections the quartz is usually highly recrystallised and is seen to form a mosaic of interlocking allotriomorphic crystals. No signs of original rounded grains of quartz or of any secondary growth around them are seen. Detrital fragments of muscovite and tourmaline are common. Biotite, Ilemmite and pyrite are seen in thin sections (Pl.37. Fig.2).

PLATE No.37. Fig.1

PHOTOMICROGRAPH OF SLATE SHOWING PLANES OF SPLITTING (KUND SLATE) x 60 . D = Direction of Splitting.

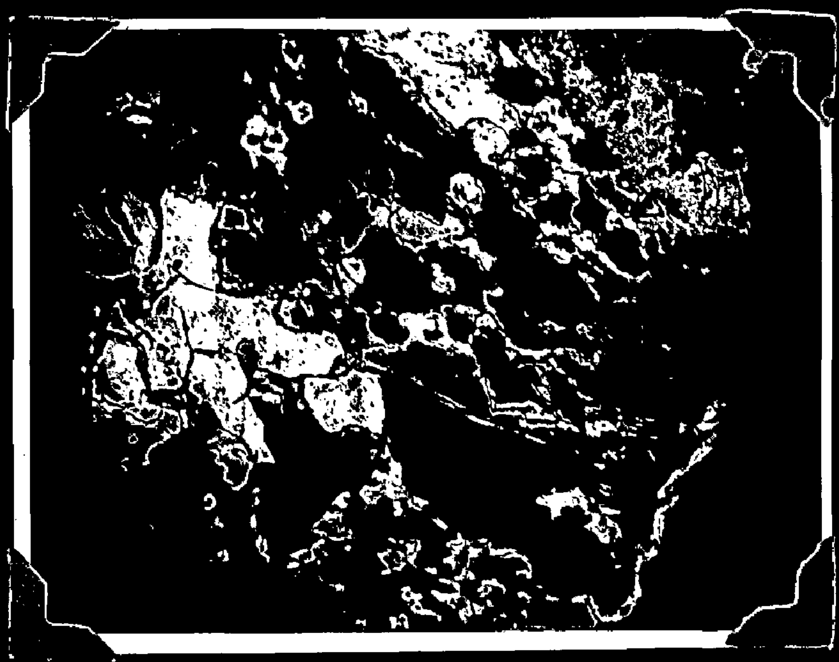


PLATE No.37 Fig.2.

PHOTOMICROGRAPH OF QUARTZITE SHOWING HIGHLY RECRYSTALLIZED STRUCTURE WITH MOSAIC OF INTERLOCKING CRYSTALS x 80.

Quartzites from Kishangarh (2Qzt) are less vitreous, less compact in texture, darker in colour and more argillaceous than those described above. It consists mainly of quartz in a closely inter-crystalline mosaic. Hematite is seen usually in small grains. Muscovite, biotite and tourmaline occurs as detrital materials. Calcite is sometimes seen between the quartz grains. Perhaps due to their greater impurity they weather more easily than those from Alwars.

GNEISSES (Darjeeling and Sambalpur)

These vary from fine grained to modertely coarse varieties. Augen structures are some times observed. In thin sections, Darjeeling Gneiss appear to be a micaceous rock containing muscovite and biotite. Horblende, garnet and tourmaline are also present. Garnetiferous gneiss from Sambalpur (2GN) is a fine grained grey gneiss of porphyritic variety. (Pl.38 Fig.1)

PHYLLITES (1PH-3PH)

Phyllites from Jambughoda (1PH) and Goda (3PH) are closely laminated corrugated phyllites belonging to the Aravalli system[52]. They have retained traces of bedding and have well developed white quartz lenticles and veins. Phyllite from Balaghat (2PH) is highly micaceous in nature. All these phyllites under thin sections are so fine that grains are hardly distinguishable. (Pl.38 Fig.2)

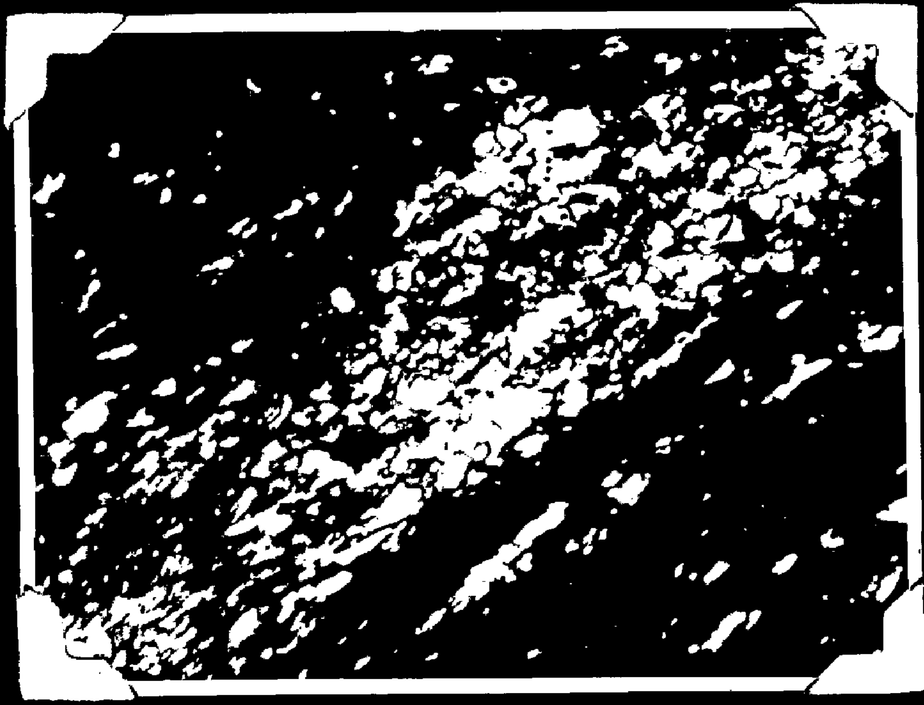


PLATE No.38 Fig.1

PHOTOMICROGRAPH OF DARJEELING GNEISS (40).

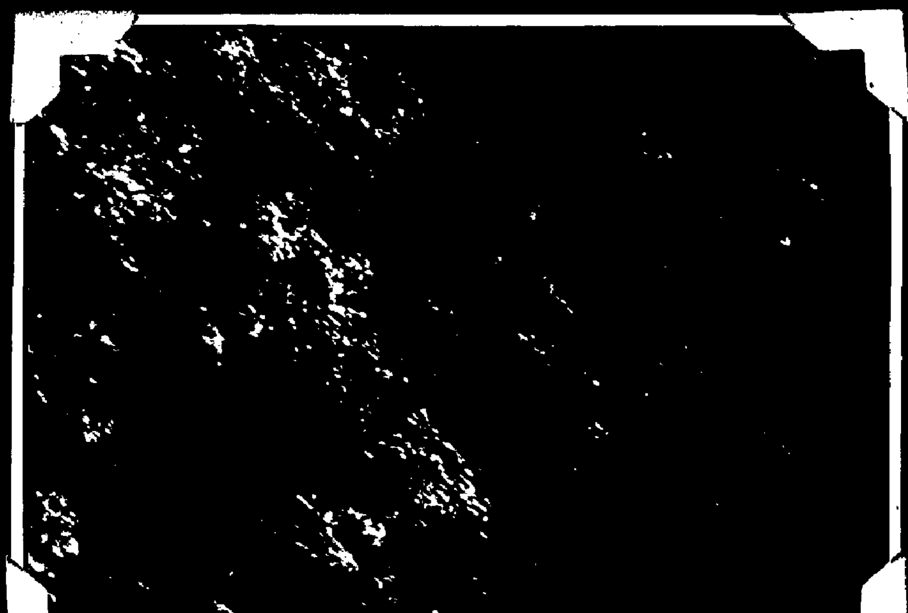


PLATE No.38 Fig.2.

PHOTOMICROGRAPH OF BALAGHAT PHYLLITE (x40)

HORN. CHLORITIC SCHIST

It is a tough dark greenish grey rock. It varies from coarse to fine grained varieties. In hand specimen it shows foliated structure accentuated by banding with coarse grained pyroxene layers. The fine grained type shows a high degree of schistosity. Under the microscope the rock is made up of largely bluish green to yellowish green hornblende and some chlorite flakes. Granular quartz, moderately basic plagioclase in lath shaped crystals and some white mica as an alteration product of felspar are seen. Titaniferous iron ore is more or less completely altered to leucoxene. (Pl.39 Fig.1). Some fissures are commonly seen and on the sides of these fissures or faults mineral surfaces appear to have taken a little polish because of sliding.

KHONDALITE

In hand specimen the rock is greyish to reddish in colour. It is foliated and exhibits numerous reddish brown garnets in a very much crushed ground-mass of the grains of quartz penetrated by sillimanite needles. Calcite, biotite, rutile and graphite are present as accessories. Orthoclase shows perthitic streaks (Pl.39 Fig.2).

The rock is very prone to decomposition especially under tropical conditions and fresh specimen are extremely difficult to obtain.

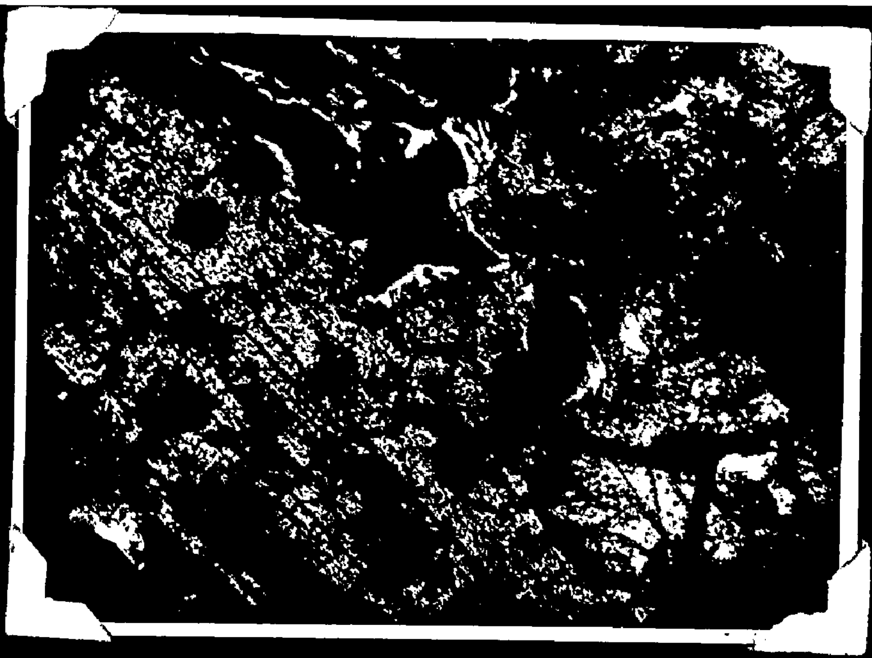


PLATE No.39 Fig.1

PHOTOMICROGRAPH OF HORN. CHLORITE SCHIST x 60.

PLATE No.39 Fig.2.

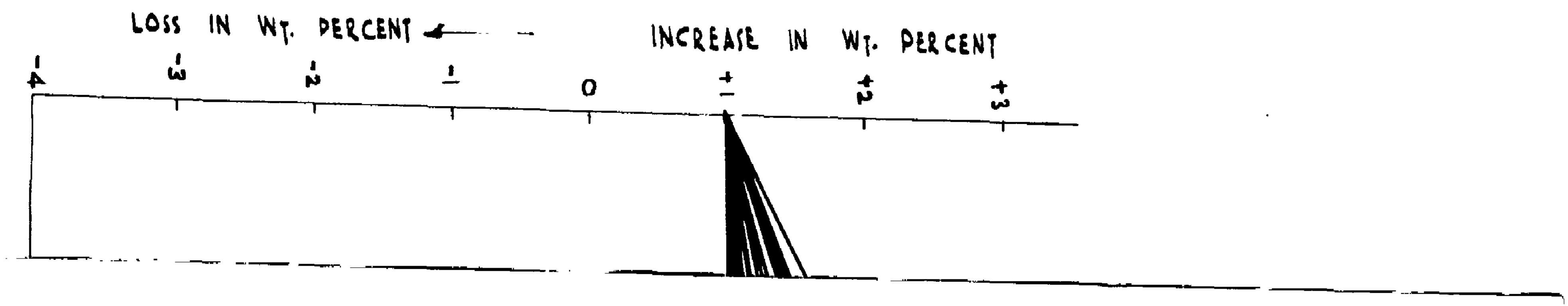
PHOTOMICROGRAPH OF KHONDALITE SHOWING RADIATING SILLIMANITE CRYSTALS (S) x 80.

CHAPTER IX.

PETROGRAPHIC EVALUATION OF DURABILITY AND THE PHENOMENA OF STRENGTH DEVELOPMENT IN BUILDING STONES

Much work has been done by Merrill[57], Anderson[58], Banies[59] Fox[60], Laurie[61], Schaffer[62], and many others[63-67] on the weathering and durability studies of natural building stones. Various accelerated weathering tests have been recommended as the criteria for assessing the field performance from the point of view of durability. Recently some of these tests have been adopted in India as standard procedures[68-69] for the determination of the durability of stones.

With a view to evaluate the efficiacy of these standard methods, and to see the influence and relationship between the physical and engineering properties on one hand and the petrographic properties of rocks on the other, stones have been tested for durability. The results have been plotted and the durability curves are obtained as shown in Figs. 32 to 35. From the study of these curves it is observed that during the performance of the test as given on page 59, certain stones such as sandstones from Dholpur, Mirzapur, Jodhpur, limestones from Chittor and Khondalities from Andhra though possess better physical and engineering properties than many other stones such as Dharangadha sandstones, Simla and Jaisalmer limestones etc., failed earlier. Further, it has been observed that inspite of the great decrease in weight in case of various stones, cracks did not appear throughout the 30 cycles, where a cycle means dipping a dired stone sample in 14% $Na_2SO_4 \; 10 \; H_2O$ solution for 4 hrs. and then drying it at 105°C in

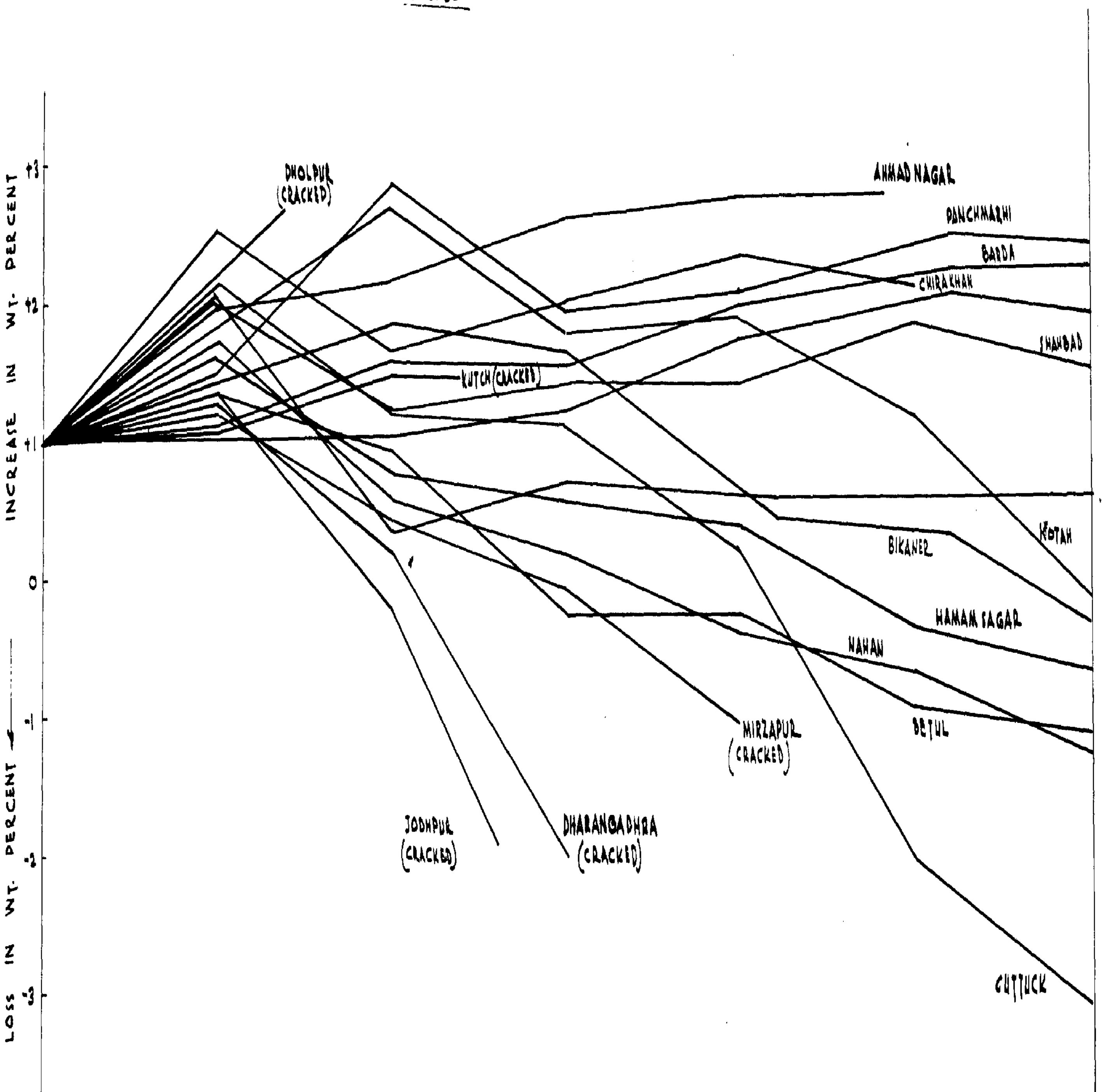

LOSS IN WT. PERCENT
INCREASE IN WT. PERCENT
-4
-3
-2
-1
0
+1
+2
+3

DURABILITY CURVES

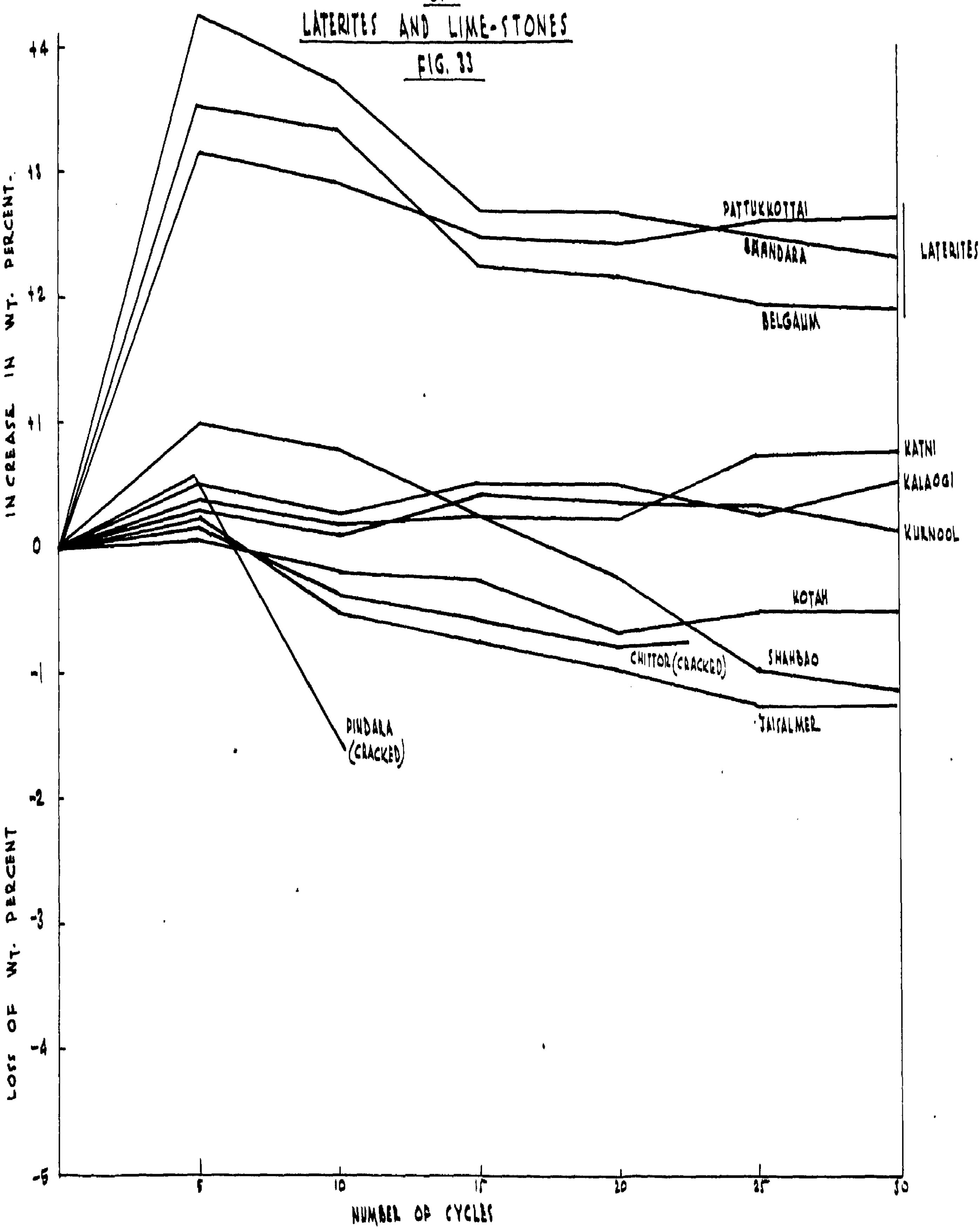
OF

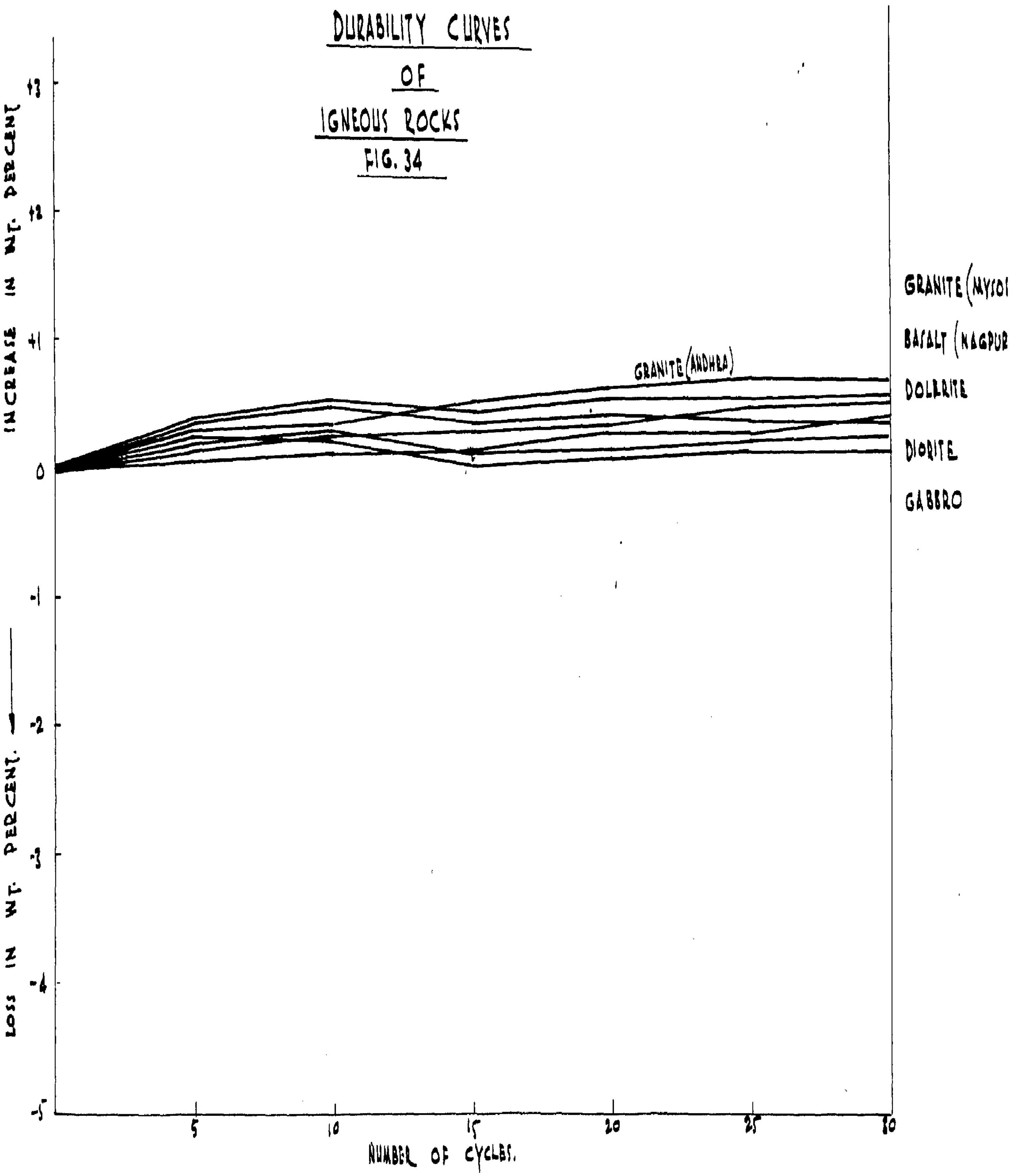
SAND STONES

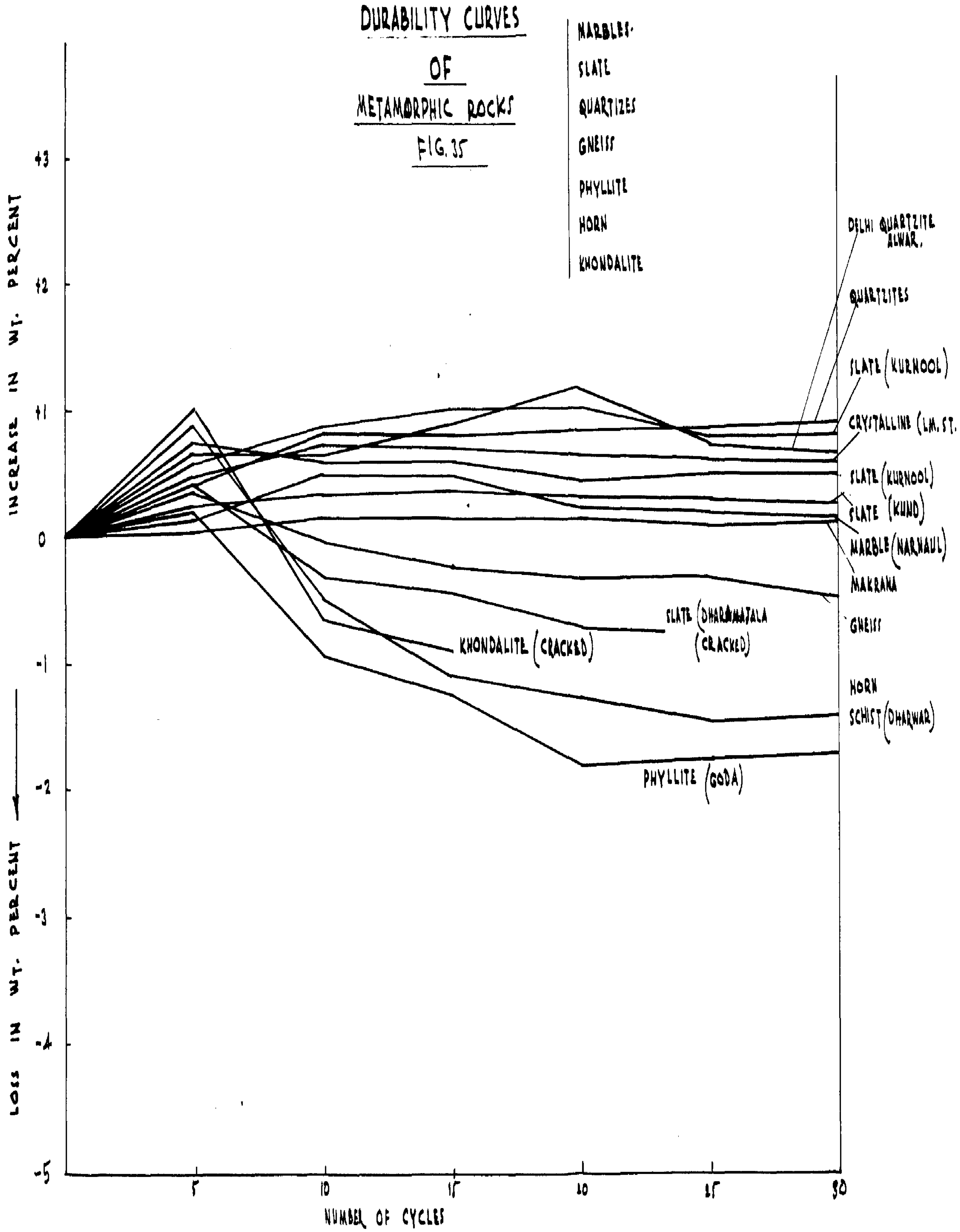
FIG. 32



DURABILITY CURVES
OF
LATERITES AND LIME-STONES
FIG. 33




DURABILITY CURVES
OF
IGNEOUS ROCKS
FIG. 34
INCREASE IN WT. PERCENT
LOSS IN WT. PERCENT.
+3
+2
+1
0
-1
-2
-3
-4
-5
5
10
15
20
25
30
NUMBER OF CYCLES.
GRANITE (ANDHRA)
GRANITE (MYSOI
BASALT (NAGPUR
DOLERITE
DIORITE
GABBRO



DURABILITY CURVES
OF
METAMORPHIC ROCKS
FIG. 35
MARBLES
SLATE
QUARTZIZES
GNEISS
PHYLLITE
HORN
KHONDALITE
INCREASE IN WT. PERCENT
LOSS IN WT. PERCENT
+3
+2
+1
0
-1
-2
-3
-4
-5
5
10
15
20
25
30
NUMBER OF CYCLES
DELHI QUARTZITE ALWAR.
QUARTZITES
SLATE (KURNOOL)
CRYSTALLINE (LM. ST.
SLATE (KURNOOL)
SLATE (KUND)
MARBLE (NARNAUL)
MAKRANA
GNEISS
HORN
SCHIST (DHARWAR)
SLATE (DHARMAJALA (CRACKED)
KHONDALITE (CRACKED)
PHYLLITE (GODA)

in an oven for 12 hrs. (details given on page 59). On the other hand the Mirzapur sandstones and Khondalites did not decrease much in weight, but failed only after 20 and 15 cycles respectively. Obviously the increase or decrease in weight of stones appears to give no indication of their durability and, therefore, it becomes difficult to judge the comparative durability of those stones which survive all the 30 cycles. The present studies were under taken for elucidating those properties of stones which though important from durability and strength point of view in a stone, remain undetected during the standard test for durability.

In addition to the above facts, the behaviour of weathering of a stone may be different for different natural weathering agencies. Since these tests give only the action of salt crystallization on weathering , it appears that they have limited scope of application. In order to have a better understanding of the factors of durability under different conditions and the phenomena of strength development in case of stones, an insight into the various aspects of their petrographic and physico-engineering properties seem essential.

PETROGRAPHIC FACTORS OF EVALUATION

Petrographically a stone may be defined as -

$$P = f\,(m, s, sh, O, p, \ldots\ldots\ldots) \qquad \ldots\ldots\ldots \qquad (1)$$

where "P" is the defining index expressed as a function of "f" of the mineral composition "m", grain size "s", grain shape "sh", grain orientation "O" and grain packing "p" and so on. Since these function decide the constitution of a stone, these chemical and engineering behaviour of stones and the subsequent changes brought about during the process of weathering. According to Pettijohn[70] The original porosity of a rock is affected by (a) uniformity of grain size (b) shape of grains, (c) method of deposition and packing of sediments, (d) compaction during and after deposition. On this basis if "W" for weathering performance is substituted in place of "P" for a particular specimen, the durability can be expressed petrographically as a dependent variable in a multiple regression equation where $X, X_2, X_3 \ldots\ldots\ldots X_n$ are the independent petrographic variables as stated above, i.e.

$$W = f\,(X_1, X_2, X_3 \ldots\ldots\ldots X_n) \qquad \ldots\ldots\ldots (11)$$

From the Ultrasonic and Sonic tests (Page 135 to 139) it appears that the physical and engineering properties of stones are ultimately the functions of their mineralogic and petrographic properties. Regarding chemical composition, it is well known that the quantitative estimation of minerals gives a better idea of the same. Hence an attempt to evaluate the durability of rocks on the lines suggested in equation (11) may form an advantageous basis.

ELEMENTS OF STRENGTH AND DURABILITY OF STONES IN ENGINEERING STRUCTURES.

Theoritically, the strength of a stone, as dependent upon the coherence of its particles might be taken to imply identical resistance to every disintegration force. On comparison of the durability curves (Fig. 32 to 35) and the general toughness curve of rocks (Fig.26) it is obvious that there is no definite parallelism between the structural strength and the durability of a rock. Though the compressive strength, modulus of rupture, shearing strength or modulus of elasticity may reach thousands of pounds per sq. inch yet it gives no idea of durability. Unfortunately the term 'durability' as defined by Scheffer[71] and others[72,73] is limited to the reaction of the chemical and weathering agencies on stone. However, 'Durability is a relative term and can only be defined here in relation to the place, climate, and other conditions existing in the field. Hence 'Durability' of a Building Stone' can be defined as "A Characteristic property of a stone with regard to its wear and tear in obedience to various physico-chemical, atmospheric and engineering forces prevalent under a particular field condition". Thus different principles of durability apply to the stones of each class depending upon the service conditions of a particular stone.

While considering the actual elements of strength such as compressive strength or shearing strength of a stone, it is evident that these properties are dependent on its constituent minerals and their arrangement. It is of consequence whether these consist of brittle, cracked quartz or of varieties of tough felspar with some tendency to rift, or fibrous hornblende or tenacious augite, or of calcite or dolomite with easy cleavage. In the trap rocks of India, such as Basalt from Nagpur, this particular property can be connected with that of the predominant mineral constituents e.g. the toughness of augite and interlocking laths of felspars. The resistance of the dolomite limestones is attributed sometimes to the strength of the mineral dolomite[74]. However, to confirm this it requires actual determination of compressive strength and other properties of the common rock forming minerals which make up the building stone. During the course of these investigations, examples of permanent flexure and deformation in many ancient constructions (Lodi Tomb' at New Delhi and Nawab's palace at Bhopal) such as the sagging of stone beams and slabs after long suspension with partial support, and the flexure of hewn blocks of marble at Makrana in quarry yards and mantles in ancient buildings have been noticed. According to Hoskins[75] under a predominant pressure in one direction, a rock which is rapidly deformed may pass beyond its elastic limit and become ruptured, but under conditions of less rapid deformation, it may simply tend to flow. This slow phenomena leading to permanent flexures show how important is the element of time in the deformation of rocks, and that, given a sufficient time, a stress below the ultimate strength may surpass the elastic limit and result in flowage, which is very important from durability point of view. With a view to ascertain the actual foundations on which these methods of trial and tests for durability and strength should rest and the chief factors on which the strength of a stone depends can be broadly classified into four classes :-

A, Interlockment or granular arrangement

B, Coherence (Cementation and Molecular cohesion)

C, Tension or Strain

D, Rigidity

A. <u>INTERLOCKMENT</u> - Three types of consolidation of mineral grains may be distinguished within a rock.

I. Irregular Aggregation - In this class the grains of sedimentary stones occur simply heaped together in a haphazard mass and are composed of fossils, grains or pebbles so irregularly disposed that each lies in mere contact with its neighbour, touching at but few points, with numerous unfilled intervening cavities, largely unsupported, for example, in the sandstones from Dharangadhra, Nathkua, Kutch, Ahmadnagar, Cuttack, Mirzapur and Dholpur Sandstones. In consequence of this irregular disposal of grains, stones of this class are likely to enclose an abundance of small or large cavities (Pl. 40 Fig.1) resulting in porous and cellular texture, inferiority of compactness and low compressive resistance. Some times the loose textures may be offset in the direction of both compressive strength and resistance to weathering due to the presence of a strong cement, lining the cavities in the form of calcite, quartz or crystalline variety of iron oxide. In such cases, even a porous rock may possess great durability, by virtue of its insoluble character. Example of this kind is found in some Nagpur sandstones (not tested here) where the cavities are lined with a cryptocrystalline mass of silica coloured with limonite. When properly interconnected the enclosed air cavities favour some times more general distribution of salts of crystallization throughout the stone which protects it from disruption, and the stone though weak, passes through many cycles of weathering.

II. Parallel Sorting - In sedimentary stones this position of grains sometimes results simply from their platy form, such as in Jaisalmer limestone. It may also be derived from partial sorting and rearrangement by wind as in the case of sand-stone from Songir. Elsewhere it may be the consequence of

PLATE No.40

PHOTOMICROGRAPH OF GONDWANA SANDSTONE WITH UNSORTED IRREGULARLY DISPOSED GRAINS (G) X 90.

sorting of sandgrains during deposit under water[70]. In the crystalline stones, whose grains have emerged from a stage of plasticity or fusion, a similar parallel disposal has been commonly produced by instense pressure. This is often represented in the gneissose rocks structure (Pl.38 Fig.1). In such cases the stone is weak and less durable in the direction of parallel sorting.

III. <u>Dovetailing or Interpenetration</u>

It has been observed that in case of Gondwana Sand stones, the mineral grains are loosly aggregated but the whole mass is sometimes traversed by strings and veins of calcite (p.142). Similarly in case of Gneisses the presence of elongated crystals of hornblende and tourmaline (P,158, PL.38) and in case of horn. chloritic schist the lath shaped crystals of felspars (P.159 Pl.39) have been noted. These minerals have settled down into parallel position along the bedding plane of the sedimentary rocks and along the direction of foliation in case of the metamorphic rocks. These elongated forms of minerals act as a reinforcement in these rocks in which they got embedded; and the phenomena of strength development can be compared to that of an addition of straw in wet mud to improve the strength of a sun dried brick. The extent of the influence of such minerals as elements of strength, appears to be proportional to their number and heightened by the associated obliteration of cavities and consolidation. In such cases the position of stability or strength of a stone is only in the direction of the bedding plane. If stones are placed along the direction of rift planes, the general parallelism of its grains and their arrangement become a source of weakness, due to the tendency of ready cleavage so imported. This in general is conformed by the values of engineering properties obtained along and across the directions of rift planes. (Table 48 to 73). The parallelism of mica-scales, which may exert a strong binding action in horizontal position, becomes a principal cause of the well known destruction of blocks of micaceous sandstones by weathering, when erected on edge in 'ashler'.

These features are still more prominently displayed in the close interlocking of crystals in the crystalline stones such as the marbles, dolomites, traps, granites and gneisses.

B. COHERENCE

Besides the strength developed by the interlockment of mineral grains of stones, two modes of coherence, (1) cementation and (2) molecular cohesion, prevail in building stones.

(1) Cementation - This is mainly present in the stone of sedimentary nature. Iron oxides, clay and silt are among the feeblest cements except when uniformily diffused in minute films among closely abutting grains - a condition in which even a feeble cement becomes tenacious. Such cements are generally heaped together in the larger cavities (Pl.41) and, to a large extent, absent or scanty among the finer interstices where alone its binding power could be effective. In case of Dharangadhra and other Upper Gondwana sandstones the low strengths are only indicative of the poor cementing power of 'Kaolimitic clays.

It has been observed in many cases of the Gondwana Sandstones that the lack of cementing power of the true clays is aided

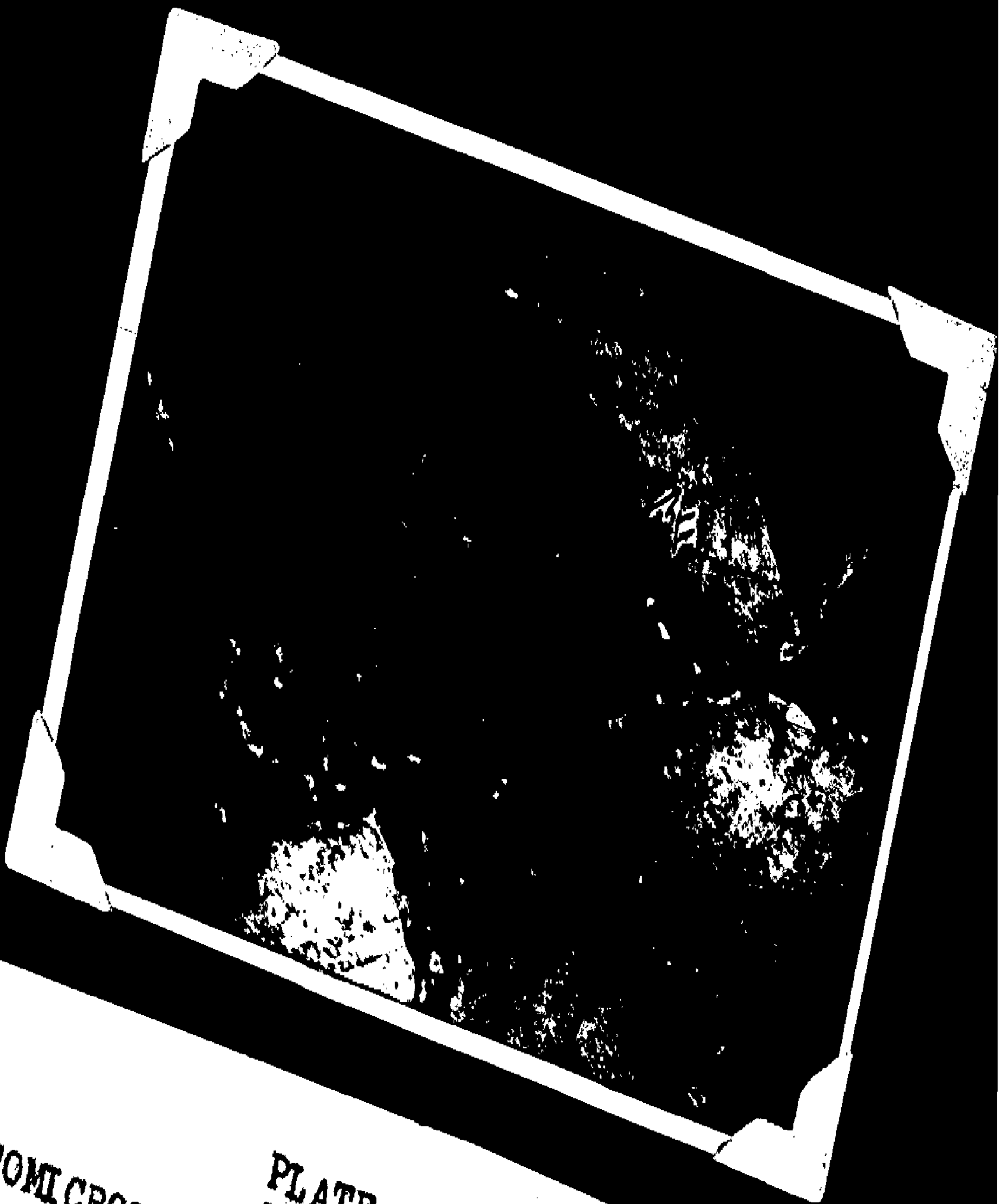


PLATE No.41

PHOTOMICROGRAPH OF SANDSTONE FROM AHMADNAGAR SHOWING CLAY CEMENT HEAPED IN LARGE CAVITIES AND ABSENT FROM FINER INTERSTICES x 90C = Cement F = Fine Interstices.

by the invisibily diffused content of lime-carbonate and not due to the visible Kaoline and iron oxides in the interstitial cement. During the course of these investigations on 'Somnath' temple repairs from Upper Gondwana Sandstones, it has been observed that the lime-carbonate dissolves out by weathering, the cementing clay softens, the stone becomes pulverulent and finally disintegrates into loose sandy mass. It has been observed by Julien[76] that the ferruginous clays, amorphous granular iron and the manganese oxides, are better cementing materials in case of sedimentary stones. The strength of these cements is due to their occurrence in crystalline form or as fibrous films and crusts of magnetite, hematite, and limonite etc. Such sandstones with crystalline cement are not common among Indian Building Stones.

From the results in engineering properties (Table 48 to 75) it appears that out of all cements the most powerful is 'Silica', which in the form of compact crypto crystalline mass binds together a large part of the otherwise loosely pulverulent sandstones of Cuddapah&Vindhyan Systems, into solid ortho-quartzites. From the point of strength and durability, these cements form the most satisfactory building stones as available in plenty in this country. Such stones are useful for acid proof or alkali proof constructions.

Even in granites and other crystalline rocks there is a good reason to suppose that some cement is often partly concerned in their strength. One evidence of this is the effervescene caused by application of an acid in some specimens, sometimes accompanied by loss of coherence and strength. Such a phenomena has been observed in the case of Kishangarh Quartzites and schists from

Dharwar and Khondalites. This testifies to the diffusion of lime, magnesia and iron carbonate through the interstices and in forms rarely detected by microscopic examination.

(2) <u>Molecular Cohesion</u> - In crystalline stones coherence is greatly increased by another physical force, the molecular cohesion which exists between surfaces of all solids pressed into intimate contact (Pl.28). In consequence of the tremendous force involved in capillary adhesion, such surfaces may cohere so strongly that on application of sufficient pressure for detachment, the very surface themselves may be torn away. This cohesion is reinforced to a small extent, about 16 pounds to the square inch by atmospheric pressure. A block of crystalline stone comprises an innumerable quantity of minute planes in close adherence. It has been observed that the increase in compressive strength generally accompanies the increasing fineness of grains, for instance in granites from Andhra and Bangalore where compressive strengths 39, 953 and 48, 248 p.s.i. have been obtained. Such high values are produced not only by more intimate interlockment of grains, but by physical force of capillary adhesion.

The marbles and crystalline limestones exhibit the same aggregation of tangent planes and correspondingly high compressive strength. It has been observed that in thin section of marbles (Pl.42 Fig. 1&2) there is no evidence of interlockment and least possible cementation, yet they have often shown high compressive strength which in case of yellandu crystalline limestone and Makrana Marbles reached 25,834 and 26,316 pounds to the square inch respectively. Even in sedimentary stones, the same increase of strength with multiplication of contact planes is often indi-

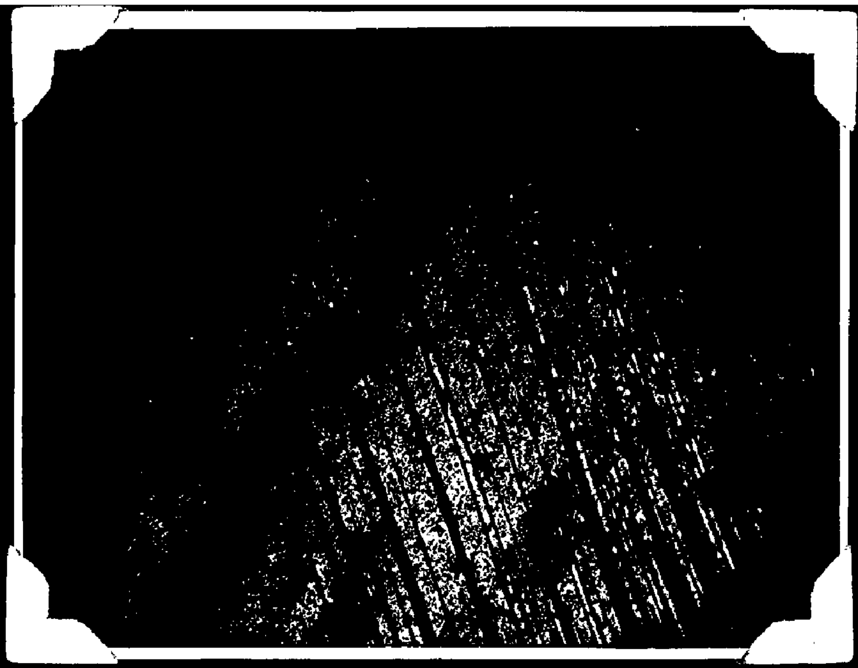


PLATE No.42 Fig.1

PHOTOMICROGRAPH OF MAKRANA MARBLE SHOWING NO INTER-LOCKMENT OF GRAINS x 120.

PLATE No.42 Fig.2.

PHOTOMICROGRAPH OF FINE GRAINED MAKRANA MARBLE SHOWING TIGHTLY KNIT CRYSTALS x 80.

cated, especially in the more finely crystalline forms of limestones from Kurnool and Shahbad, compact sandstones of Vindhyans and quartzites from Alwar.

In argillaceous varieties of limestone from Pindara (Gujerat) the compressive strength is 10,790 p.s.i., but the absorption of moisture by the clay and the oxidation of its iron protoxide produce a softening, cracking and disintegration, hastened by alternation of soaking and drying, as a result of which a failure occured only after the completion of 10 cycles (Fig.33)

C. TENSION OR STRAIN

On the basis of petrographic examination of Igneous and metamorphic rocks it appears that there is always a certain amount of balance of stress or strain among the mineral components of stone. Any disturbance of this by increase, loss, expansion contraction or ~~in [illegible]~~ by any change, tend to injure the tenacity coherence and permanence of the aggregate of minerals in a building stone. As a result of these studies the strains in a rock may be classified as - (1) Strains by crystallization, (2) Strains by Substerranean stresses and (3) Strains due to changes in temperature.

(1) Strains by Crystallisation -

The microphotograph of an ordinary building stone, such as that of granites (Pl.28 to 30) unveils clearly a struggle of growth among its crystal components i.e. quartz, orthoclase, albite and hornblende etc. It seems that all are thrusting and straining together for development within the original plastic mass or magma, probably from its own centre of pressure, until the process of consolidation and rigidity came to an end.

This mutual conflict is shown by the total absence of minerals which have perfected their crystal faces in these rocks. Further all minerals lie interlocked and jammed together with rough and irregular outlines. At the ~~in~~ bounding planes between the individuals, evidence of mutual pressure or stress and consequent strain are found in case of igneous rocks. Under the microscope ample centres showing the survival of these still active stress are commonly seen (Pl.43 Fig.1)

In Vindhyan sandstones which possess a crystalline silica cement, the grains appear to have been wedged apart by a strong force (Pl.43 Fig.2), during the process of crystallization of the interstitial cement. In such cases where the minerals are under tension or strain, the whole structure of the stone rapidly begins to fall, on the application of some sudden tensile or compressive strain, and effects the durability.

(2) Strains produced by Subterranean Stresses

In consequence of the uplifting and folding the rocks have been everywhere left in a state of strain. A bending of strata would tend to cause tension near the convex surface of a fold[77] As a result of this, cracks radiating apparantly from points of concentrated pressure and rifts indicating slightly opened cleavage planes are common features in the field. Broken crystals of quartz and felspar squeezed down into eye shaped or lenticular flakes giving rise to "augen structures" (Pl.44 Fig.1) testify to the heavy strain under which they have been pressed.

According to Barus[78] in the case of metals, the energy applied in the straining has been in large part stored up in per-

PLATE No.43 Fig.1

PHOTOMICROGRAPH OF SYENITE FROM KODIYALA FELSPAR CRYSTALS UNDER STRAIN S = Strain Shadow x 80.

PLATE No.43 Fig.2.

PHOTOMICROGRAPH OF VINDHYAN SANDSTONE SHOWING QUARTZ GRAINS WEDGED APART WITH SILICA CEMENT (S. Cem.) x 120.

manent tensile stress or "potentialized", e.g. to the amount of 50% in "glass hard" steel, strained to the point of rupture, 40% in brass; 25% in copper. This shows that in strained minerals energy is also probably potentialized. It is due to this phenomena that in the sedimentary strata of gentle flexures and those near the surfaces i.e. relieved by erosion from their original superincumbent load, that the quarrymen search for most easily and satisfactory working of building stones for construction. It is in these they find evidences of unsatisfied stress which helps them in quarrying the deposits. Such cases are found more in the quarries of compressed granites and charnockites and crumpled gneisses and limestones belonging to the basement complex of India. From Ultrasonic and Sonic determinations it has been observed that these materials possess a higher modulus of elasticity (Chapter VII) than the arenaceous or argillaceous sediments. In such rocks under the microscope the minerals display "strain shadows" (Pl.44 Fig.2) which are significant of the active stress yet remaining and the same may be pertinent to engineers. Regarding the survival in still active form, of a part of the enormous force of compression which has been exerted, the quarry masters have full proof in symptoms of strain ~~and~~ still remaining in the strata among which they are working, especially in ~~g~~ granites and other crystalline and massive rocks.

(3) Strain due to change in temperature

By changes of temperature caused by the vicissitudes of climate it is evident that great variations of tension must be generated in masses of building stones. These changes take place not only between its superficial and deeper layers, but are more

PLATE No.44 Fig.1

PHOTOMICROGRAPH OF GRANITE SHOWING BROKEN PIECES OF QUARTZ AND FELSPAR SQUEEZED INTO EYE SHAPED STRUCTURE x 90.

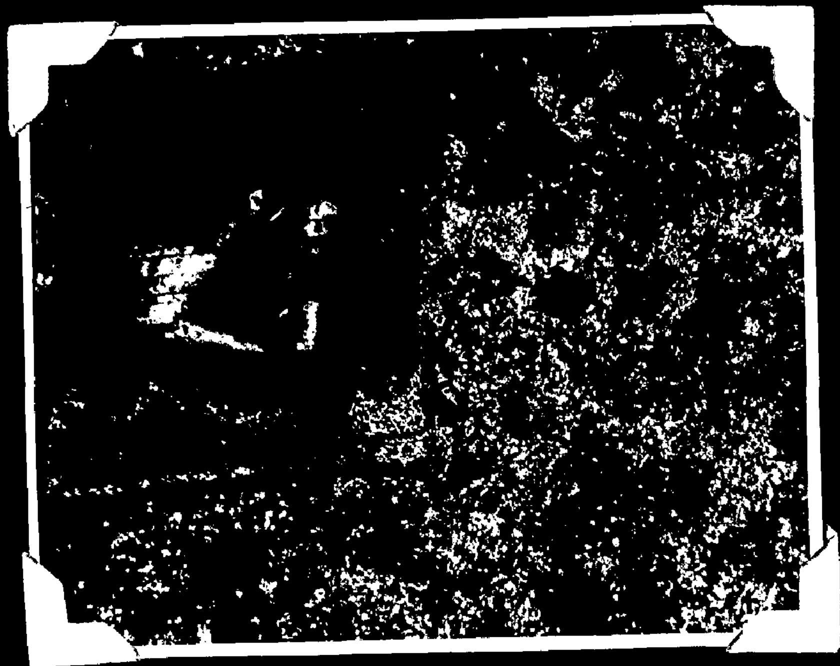


PLATE No.44 Fig.2

PHOTOMICROGRAPH SHOWING FELSPAR WITH STRAIN RINGS (S.R) x 120.

variant between its component mineral grains due to the difference in amount of expansion. 'Sugaring' or granulation which is the main cause of the weathering of marble in the Indian Building results from the differential thermal expansion of tightly knit crystals of calcite (page 155). This is a process by which inter-crystalline bond is broken.

The latter forces in conjunction with the forces due to 'Tension or strain, as discussed above, play a very significant role in the weathering behaviour of stones in Indian buildings and this factor needs full appreciation in any test framed for the purpose of durability.

D. RIGIDITY

During the course of experiments on engineering properties it was observed that certain stones like charnockites yielded under compression suddenly like a mass of glass at a particular pressure. This property in case of rocks is perhaps due to the rigidity or in other words due to the lack of plastic deformation capacity. This is of great importance from the durability and strength point of view, where stones are subjected to great pressures in engineering projects. Any plastic deformation of a rock is bound to disturb the completeness of original interlockment and cementation, leading to permanent disruption. Besides the disturbances in mutual interlockment even the mutual bonds between the individual mineral grains get loosen ed and ultimately effect the durability. There are mainly two ~~causes of~~ plastic factors which can be considered here from the durability point of view especially when a stone is subjected to great compressive forces.

(1) Cleavage and Gliding planes, (2) Sliding surfaces.

(1) <u>Cleavage and Glidding planes</u>

Coarsely crystalline marbles from Makrana, Motipur (Gujerat) and Devimata (Rajasthan) in which the individual grains are sometimes 2 mm. to 5 mm. in diameter have generally given low compressive strengths ascompared to other varieties. The grains show (Pl.42 Fig. 1&2) twinning striae parallel to the crystal. The gliding of the molecules ~~over~~ of one plane over another produces weakness in the grains.

All easily cleavable and frequently twinned minerals such as felspars, hornblende, calcite etc., from this point of view, are possible sources of weakness, in proportion to their abundance in any building stone. So is the case in the granites with the twinning which is equivalent to gliding planes, in triclinic felspars.

(2) <u>Sliding Surfaces</u> - The innumerable open fissures and clifts, often with smooth polished surfaces, occur not only within the rock mass (Pl.45 Fig.1) but between the grains of stone subjected to great pressures (Pl.45 Fig.2). The well known forms, like fissures, faults, and slikensides etc. have also been observed to a small degree by the enormous distribution of microscopic polished surfaces, and small microscopic faults (Pl.45). This structure developes a grave source of weakness in building stones, and therefore concerns the architect, engineer and builder seriously. This justifies the necessity of tests and precautions yet needed to guard against the danger of this concealed characteristics of the structure of stone.

PLATE No. 45 Fig.1

PHOTOGRAPH OF CHIRAKHAN SANDSTONE SHOWING OPEN FISSURE X 60.

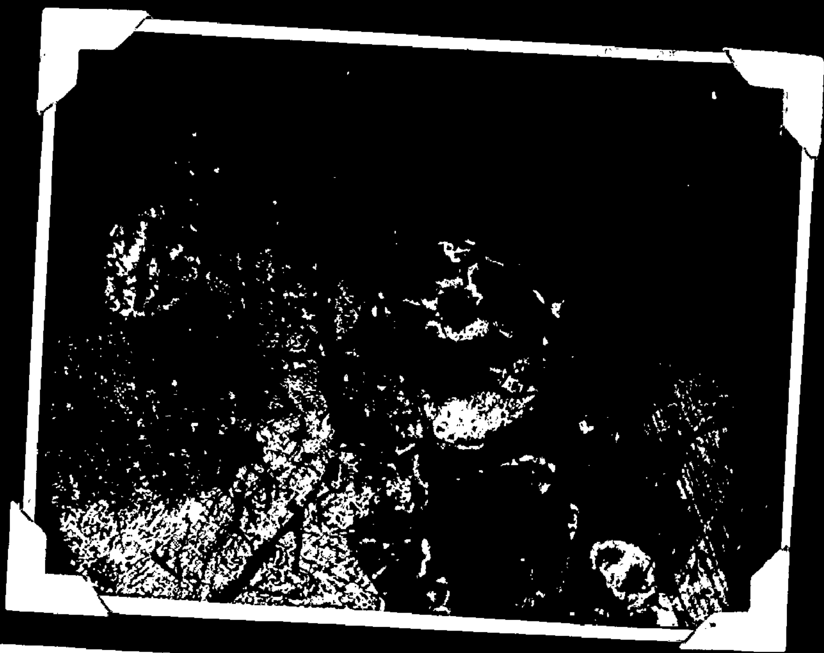


PLATE No.45 Fig.2.

PHOTOMICROGRAPH OF GRANI E PORPHYRY (MYSORE) SHOWING FISSURES (F) FAULTS, (F-F) POLISHED SURFACES (P) ON MICROSCOPIC SCALE x 120.

SEASONING OR LATE DEVELOPMENT OF STRENGTH IN BUILDING STONES

It has been observed that some stones, soon after they are cut and dressed after extraction from the quarry face and removed to despatch yard or even during transportation to the sites of construction or market, quickly harden and develops better strength. This phenomena of strength development on exposure and drying out of quarry sap or natural interstitial juice of a building stone so peculiar and common in laterite blocks cut and dressed at western coast of India, is not yet fully understood. However, such facts indicate that the grains of even a crystalline building stone owe their mutual coherence, and the rock its strength, in part to cementation by films of solid matter deposited in the interstices from infiltration solutions or quarrysap.

It is not known with certainty as to what is the nature of this important liquid - often the very life blood of the building stone. However, on conjecture it appears (with high probability) to be due to the deposited films of lime, magnesia, iron and magnese carbonates and iron and manganese Oxides, which are common. Lime sulphate and silicates of soda, potash, lime, magnesia and other bases and even dissolved colloid silicic acid, crystallizing as quartz or in the amorphous form of chalcedony or hyalite, also generally serve as a factor in the phenomena of cementation in due course.

CHAPTER X.

STONE MASONRY IN INDIA. ITS DEFECTS AND DIFFICULTIES

Surprisingly, much work has been done only on the weathering characteristics and the methods of testing building stones. As a matter of fact, this requires less attention since most of the stones are superior to all other structural materials. Besides the durability of stones, the life of a stone building is equally dependent upon the method of masonry. Hence, the subject of 'Stone Masonry' is no less important, but it has remained a neglected chapter, and there is no standard published method on the subject so far. In the following few paragraphs an attempt has been made to initiate the problems on this subject by just recording a few experiences and observations gained during the survey and investigations in connection with the present work. Further, specification of constructing stone- trusses and the method of laying slate roofs in India have been proposed.

There are definite evidences in history to show that the art of 'Stone Masonry' in India is perhaps as old as the civilization itself. Ruins of the buildings of 'Ancient India' are the protected monuments of the great 'Stone Mason's Art', which existed in the remote past. From the time of Ashok to the 'Moghul Period' we find master-pieces of the art in stone masonry. 'Taj' the finest of buildings, the mind of man has conceived, stand today as a witness of the unsurpassed stone mason's art. Unfortunately the technique was only a matter of individual experience gained through ages and passed on from person to person. The tales are still prevalant that the hands of the builders of 'TAJ' were amputed to avoid duplication. Consequently, the art died with the experts.

The present day position is very disappointing. There is a great deterioration in the standard of stone workmanship and even the common defects are not properly cared for. Building contractors have had less and less experience in stone construction and are, therefore, less willing to undertake it, especially because they are not able to find the masons.

No doubt, the correct choice of a stone and the knowledge of compatibility of the same for a particular structure, is a little beyond the domain of a stone mason. Moreover, it is purely a matter of individual taste based on the tradition of a particular place. For example, in Delhi no other stone finds so good a choice as the red and buff coloured Vindhyan sandstone. However, the mason on site must be able to reject or select the right piece for a particular place in the structure.

Regarding the development of local structural designs much does not depend upon a stone mason, but the requirements and the availability of stone from local resources has a profound influence over it. In areas where stone alone is available (like Rajasthan and Black Cotton Soil areas of India) stone has been used for residential purposes. This gave a form of structure satisfactory in use and amenity which varied from locality to locality, depending upon the availability of stone. Some of the local forms of construction so developed are given below.

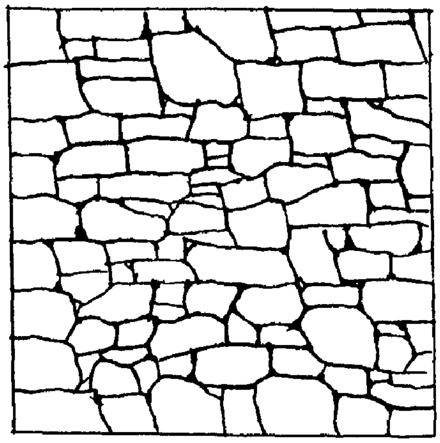
STRUCTURAL FORMS - In the external wall facings 'Stone' is used in three main forms - (i) as rubble in a solid wall, (ii) as rock faced courses in the outer skin of a cavity wall, and (iii) as ashlar in the outer skin of a cavity wall. Illustrations of various forms of walling, usually defined by local customs are given in Figures 36 & 37.

In Ashlar walling, the method of construction has been broadly the same as for Rubble walling, except that the facing stone were of rectangular blocks sawn to shape. ar

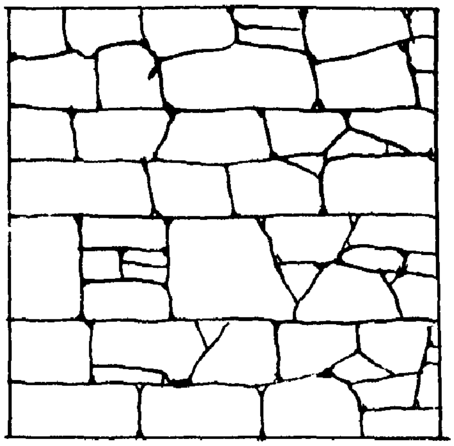
DEFECTS IN STONE MASONRY IN INDIA

As pointed out earlier, the art of stone masonry in India is gradually dwindling down. In absence of any standard specifications of the methods of construction, number of common defects have been noted and the same are mentioned below with a view to be of help to those who lay down the standard methods in future. m

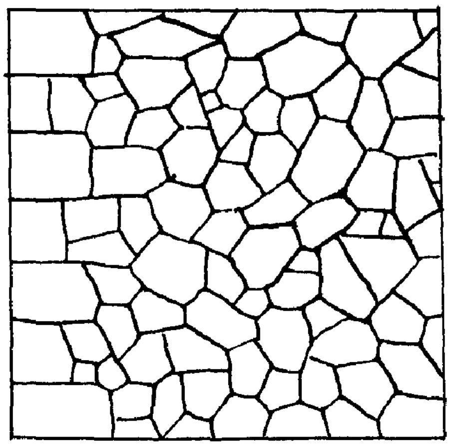
(1) Most of the masons to-day have little idea of natural bedding planes in stones and inadvertently place them in a face bedded position. The stone should never be placed face bedded (the bed lying parallel to the face of the wall) but should be laid on its natural bed except in cornices, copings and string courses where joint bedding with the bed parallel to the vertical joints is some times preferable. It is well to observe this rule in laying most kinds of sandstones and for lime-stones in which seams of good



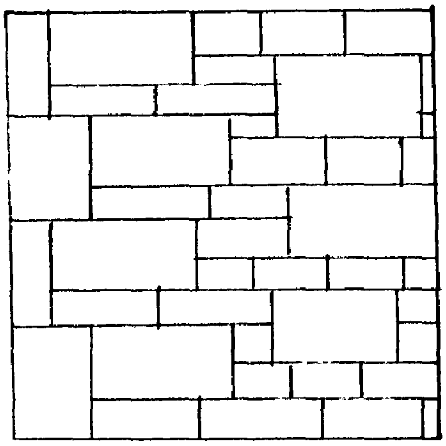
COMMON ROUGH UNCOURSED OR RANDOM, RUBBLE.



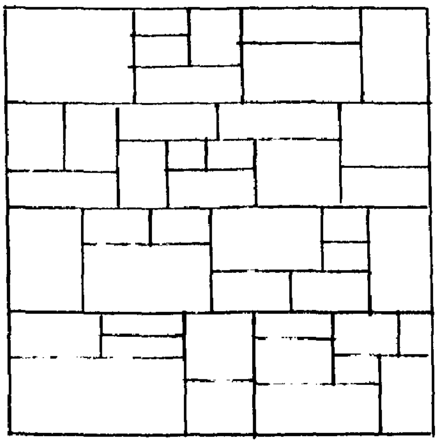
RANDOM RUBBLE BUILT TO COURSE.



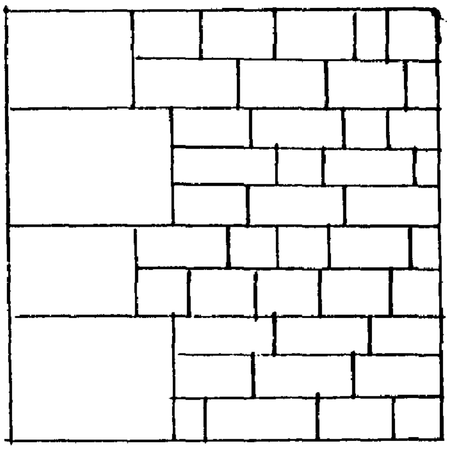
POLYGONAL RANDOM RUBBLE WITH HAMMER-DRESSED JOINTS.



IRREGULAR COURSED, SNECKED, OR SQUARE RANDOM, RUBBLE.



RANDOM RUBBLE BUILT TO COURSE WITH BEDS HORIZONTAL AND JOINTS VERTICAL.



COURSED RUBBLE.

STRUCTURAL FORMS OF WALLING.

FIG. 36

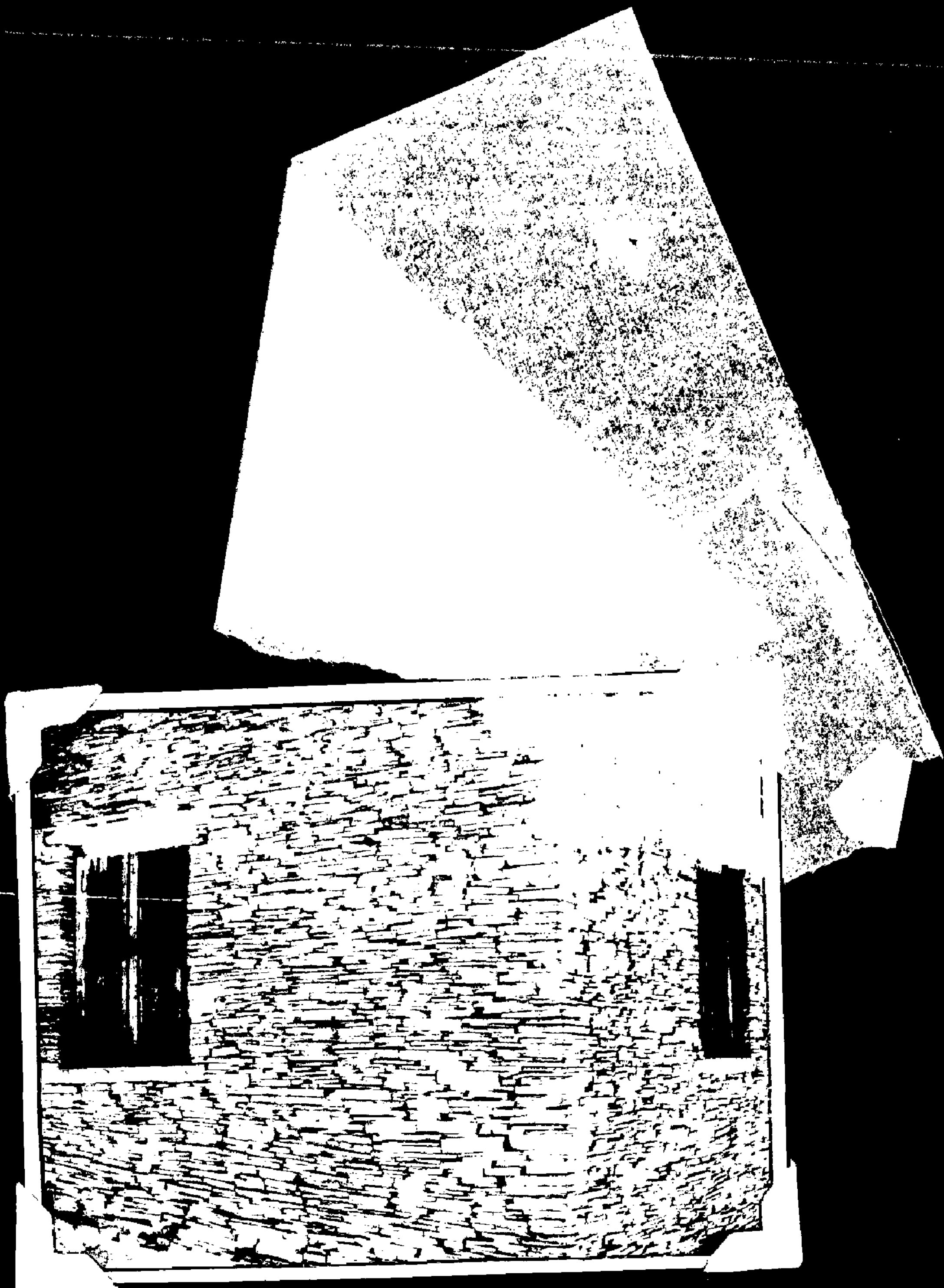
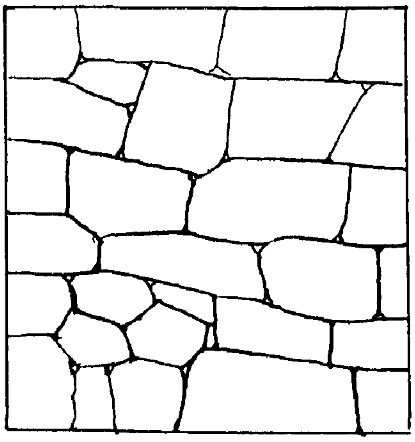
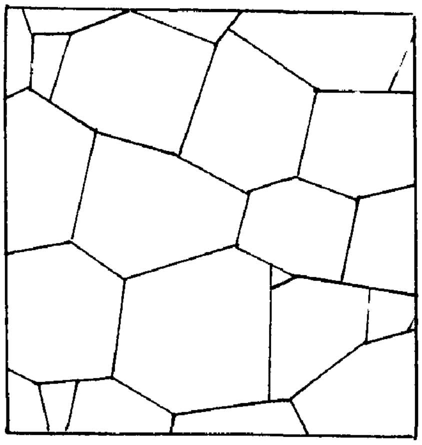


PLATE No.46

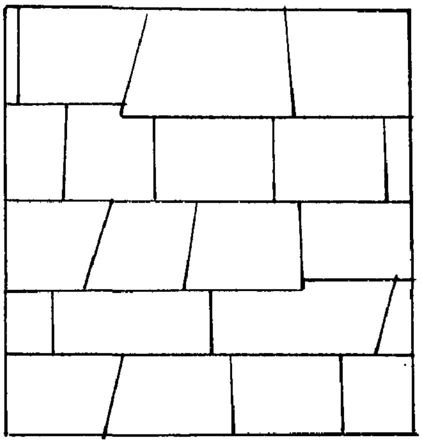
STRUCTURAL FORM DEVELOPED FROM SLABS WHERE NO MORTAR IS FOR ORDINARY
NEEDED. (RAIGANJMANDI)



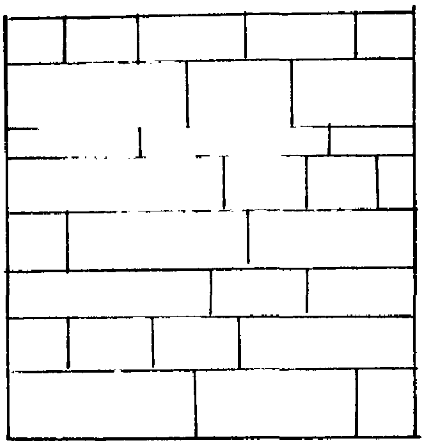
CURVILINEAR MASONRY.



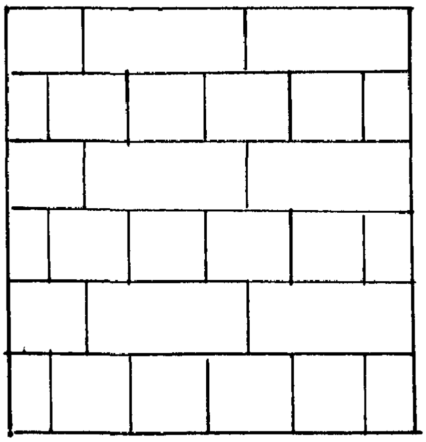
POLYGONAL MASONRY



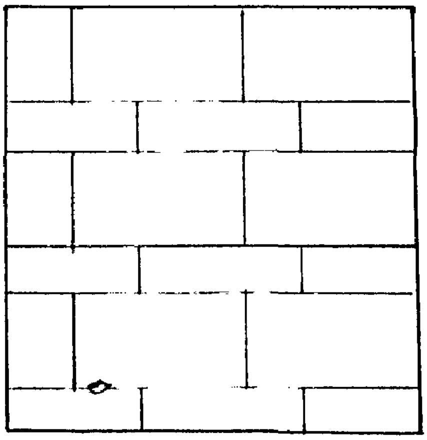
RECTANGULAR & TRAPEZOIDAL MASONRY.



RECTANGULAR MASONRY



ALTERNATE ROWS OF LONG & SHORT OF BLOCKS.



PSEUDISODOMIC MASONRY, ALTERNATE ROWS OF DIFFERENT THICKNESS.

STRUCTURAL FORMS OF WALLING.

FIG. 37

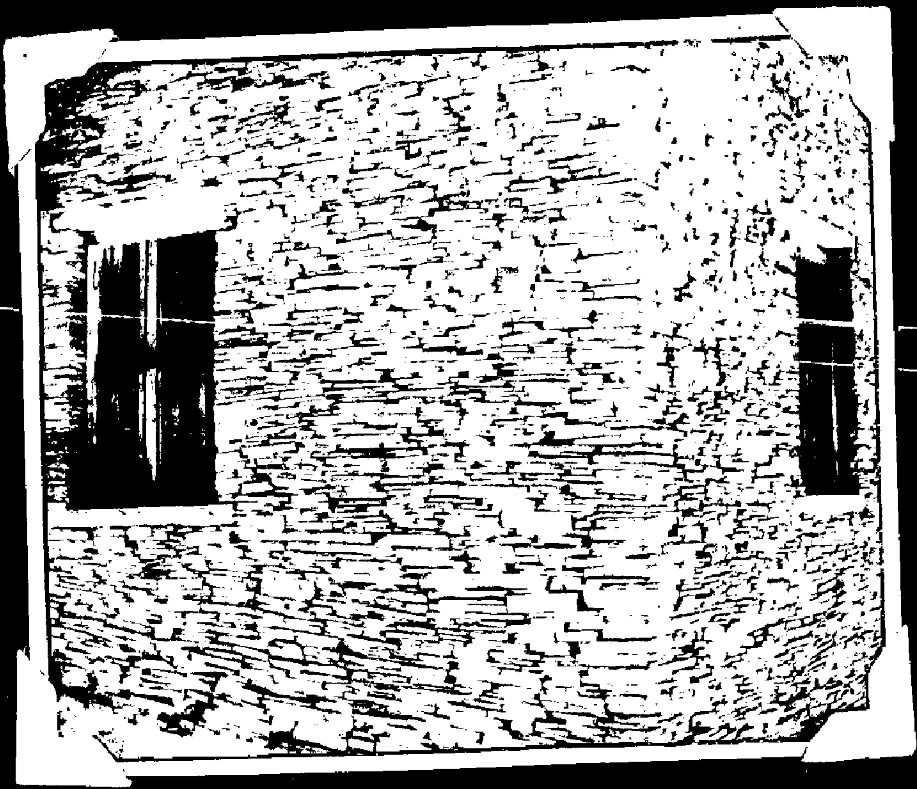


PLATE No.46

STRUCTURAL FORM DEVELOPED FROM SLABS WHERE NO MORTAR IS NEEDED. (RAMGANJMANDI) FOR ORDINARY limestone alternate with thin seams of clay. It is less important for stones of more uniform structure like Granites and Basalts.

Face bedding more often results in scaling (Pl.47 Fig.1) though necessarily it may not always be sign of face bedding alone. Scaling can also occur when the stone is laid on its natural beds (Pl.47 Fig.2) but chances are no doubt scarce.

(2) Thresholds and steps are subject to considerable traffice and abuse during construction and should always be completed only in the finishing stages of the building.

(3) Choice of proper colour combination of stones is a great factor which requires serious attention. For example, 'Kotah Stone' flooring tiles have various shades available with them and various colour schemes have been used at various important places in India, but the desired effect is achieved only at a few places.

The art of placing these stone tiles in combinations with mosaic jointings add to the grandeur. (Pl.48).

(4) Preparation of mortar for jointing and pointing requires great care. Colour and texture should harmonise with that of stone.

PLATE No.47 Fig.1

FACE BEDDING OF STONE RESULT IN SCALING(S)
(RED FORT, DELHI)

PLATE No.47 Fig.2

SCALING SOMETIMES RESULTS WHEN STONE IS LAID ON
NATURAL BED (RED FORT, DELHI)

Mortar for Rubble masonry should be more plastic than for Ashlar or Brickwork. W/C ratio should be carefully adjusted depending upon the type of masonry and the nature of stone.

(5) Stone facings are often spoiled by mortar droppings or by cement slurry, which is difficult to remove later on (Pl.49 Fig.1)

(6) Because of poor mortar solutions often leach out and the difference in colour disfigure the face of the stone (Pl.49 Fig.2).

(7) In coarse Ashlar where stone is roughly dressed, cavities in joints are often left unfilled by mortar, (Pl.50 Fig.1)

(8) Where 'Stone' sills are used in place of pre-cast sills, they should not be solidly bedded in the first instance. It is advisable to have the bed joints open till the jambs have been completed which will avoid the risk of cracking due to settlement of jambs. The bearing of sills and lintels should be somewhat longer than brick work, preferably less than the thickness of the wall and supported in full stones.

(9) Sliding joints between stone masonry wall and R.C.C. roofs need to be more efficient than in brick walls. A seperating layer properly laid would generally suffice in most cases. It should, however, be continuous at all points of contact to provide effective seperation.

PLATE No.48

STONE TILES IN COMBINATION WITH MOSAIC JOINTINGS.

(10) Projecting horns for fixing doors and windows generally work loose in stone rubbel work. Instead, rust-resistant metal clamps may be utilized.

(11) Double scafolding is prescribed but rarely used in practice; instead put logs are inserted at random forming a source of weakness. It is advisable to designate positions for put logs and use adequate transverse bond stones above the put logs to permit easy withdrawl. The back filling of put log holes may consist of stone chips (1" to 2") to ensure proper filling and adequate bond for plaster.

(12) Except in the case of stones intended for use as flagging lintels etc., very little attention is usually paid to the transverse strength of the stone. As may be seen in the walls of many buildings the stone, in actual construction fails under transverse strains. Theoritically, a building should be so designed as never to subject its wall material to anything but a direct compressive strain. However, in practice, the case is very different. Owing to bad masonry work, transverse strains do frequently occur, and their effect is shown by vertical cracks in the poorer or weaker stones of the walls.

DIFFICULTIES IN STONE MASONRY

Besides various defects which get incorporated in a stone building due to bad masonry, there are some difficulties which require serious attention.

PLATE No.49 Fig.1

MORTAR DROPPINGS (M)

PLATE No.49 Fig.2

MORTAR LEACHING AND DISFIGURING THE STONE FACE.

(1) The trap rock besides its dark colour and great toughness thero is a tendency to break on blasting into masses whose size and shape render them unfit for use as dimension stone. This problem concerns an advance in quarrying techniques.

The factors which render the traps generally unserviceable for certain structural purposes are of advantage for others. They are largely used as paving blocks and in the form of crushed stones as road metal, railway ballast and concrete aggregate. For all theso purposes darkness is no disadvantage, while density, strength and toughness are of direct service.

(2) In Deccan trap areas of India, marble clips are very costly because of the huge freight incurred on them in bringing from Makrana (Rajasthan). In order to solve this difficulty, experimonts have boon conducted during this work where 'Black Trap' was reduced to chips and the 'terrazo tiles' made. On polishing the tiles it has been seen that the 'Trap Chips' take equally a good polish as compared to marble chips (Pl.50 Fig.2) Hence trap chips can be successfully utilized in place of marble ones.

(3 Production of uniform size stones is costly, hence the difficulty of laying remains unsolvod as compared to the bricks.

(4) The thinner walls do not call for substantial foundations as the heavier stone walls.

Fig.1

CAVITIES IN JOINT

COARSE ASHLAR MASO

Fig.2

SURFACE PHOTOGRAPH OF

A MOSAIC TILE MADE FROM

[illegible]

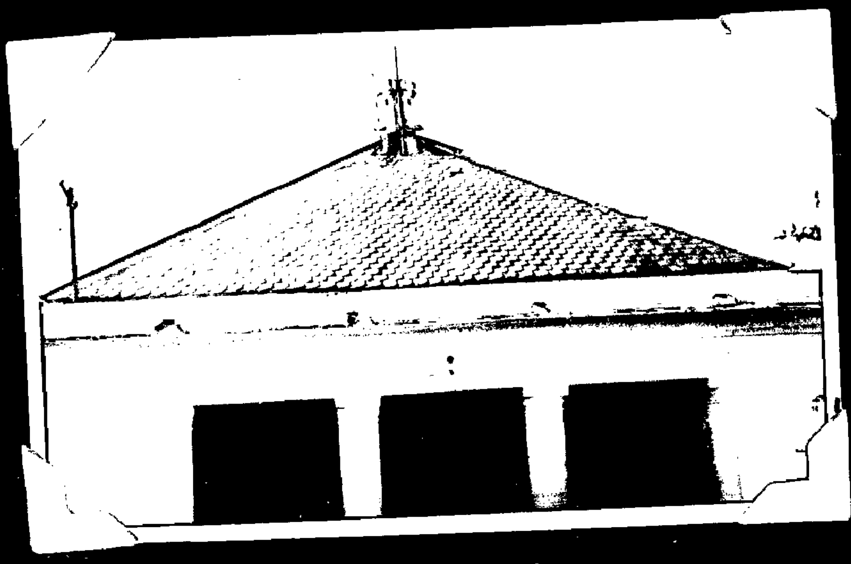


Fig.3.

SLATE PENT ROOF

PLATE No.50

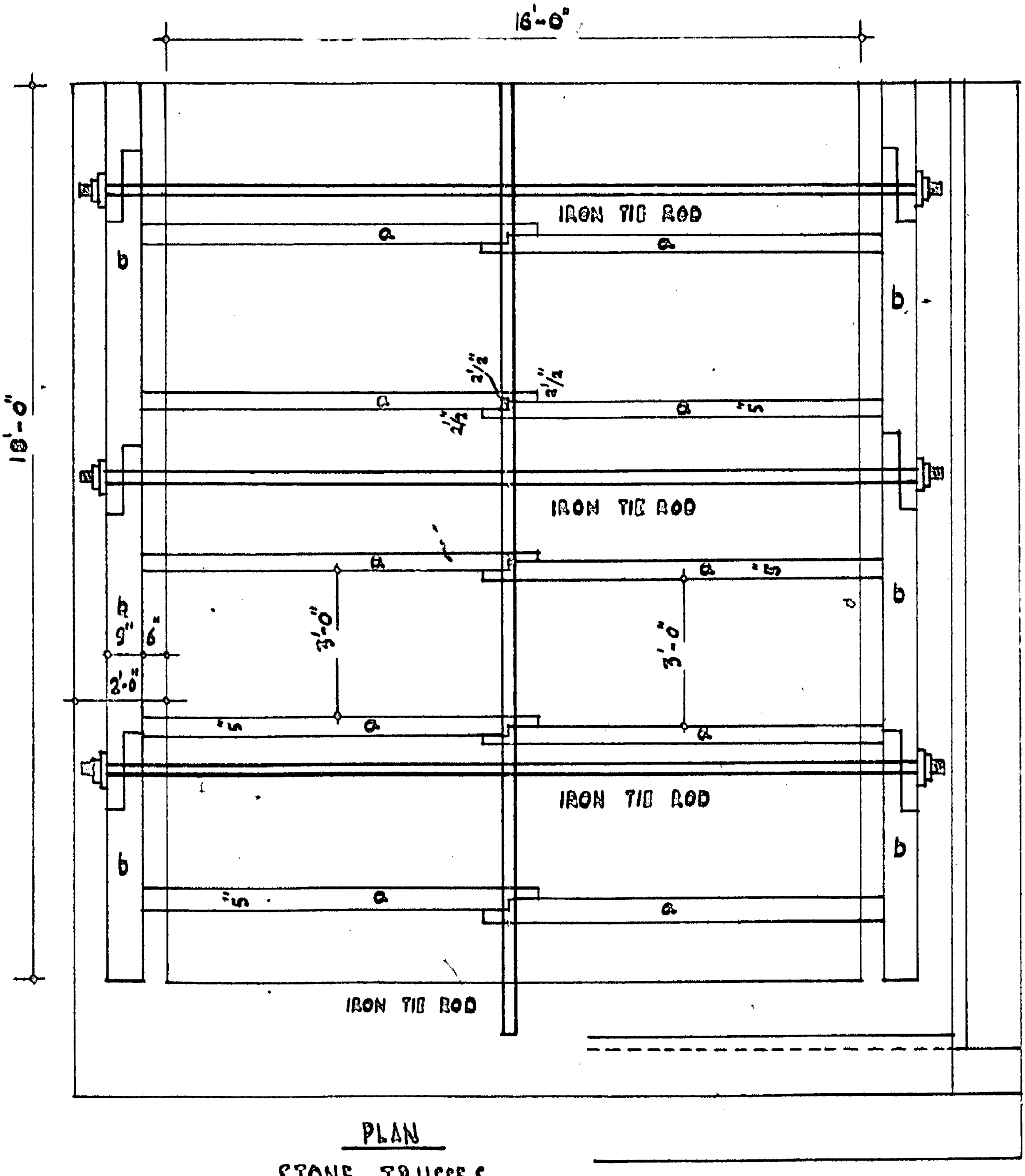
(5) Problem of preparation of stones suitable for building in thin outer leaf is a difficult and costly process.

(6) In all cases and particularly in the Rubble walled house, the high cost of window, doors and other stone dressings is an important factor.

During the field survey in connection with the present work, it was realized that stone beams of all kinds are plentiful in India and very useful trusses can be made from them. Hence a design of trusses where stone beams can be utilized, has been suggested. Similarly, slate roofs are quite common in India, but every roof is made in a different style and haphazard way. This reduces the very life of a slate roof besides the frequent maintenance expenditure and trouble. With this in view a correct method of laying slate roof under Indian Conditions have also been proposed here.

I. PROPOSED DESIGN FOR STONE TRUSSES.

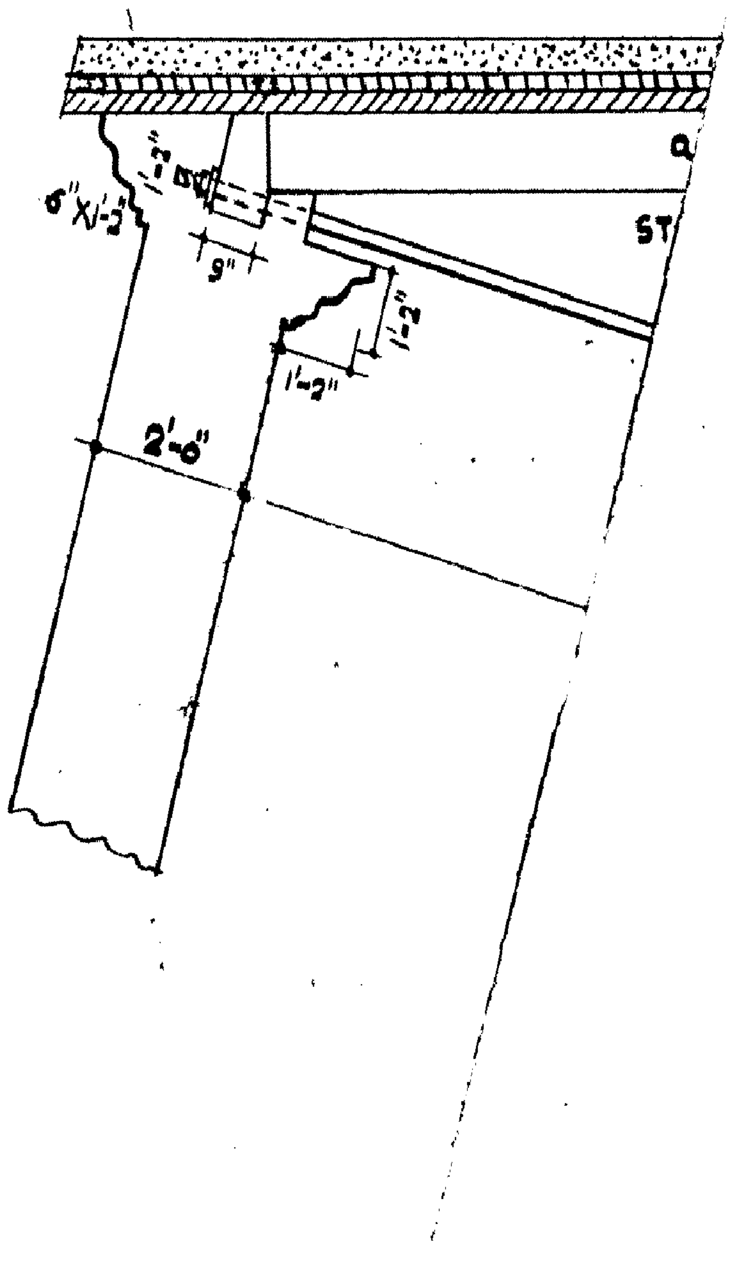
Stone beams upto a span of 20 ft. can be used with facility. The rafters consist of stone beams 12 to 5 inches thick, placed 3 feet apart. (Fig.38 & 39). An iron rod rums through holes pierced in the end, and serves as a kind of ridge rod to keep them in position. Stone wall plates, shaped as shown in figure, keep the feet of rafters in their places, and are tied together at intervals by iron tie-rods. The roof covering may consist either of a double layer of slabs breaking joint and terraced over, or of a single layer terraced and then covered with tiles.



PLAN

STONE TRUSSES

FIG. 38.



6"X1'-2"
9"
1'-2"
1'-2"
2'-6"
Q
ST

II. METHOD PROPOSED FOR LAYING SLATE ROOFS IN INDIA

Under the Indian conditions of extreme climates slate roofs are best suited. In northern India slates of Ajabgarh series quarried at Kund near Rewari have been used widely for roofing purposes.

The slates selected for Pent-Roofs should be perfectly flat, properly squared and well dressed in firm sizes and not liable to fracture when holed. These should be tough, hard, sonorous, free from falws or cracks, non absorbent, uneffected by atmospheric acids. The presence of moderate elasticity in these slates prevents derangement on roof by high wind, snow storms or the monkeys.

<u>Sizes</u> - At present slates are cut to fixed sizes and called by special names, as 'Duchess' (24" x 12") 'Lady' (20"x10") "Countess" (16"x 8") etc. They vary from one fourth inch and upwards in thickness. Small slates suit small roofs, pinnacles, turrets and curved portions. Usually the slates used are in 20"x10" and 24"x12" sizes.

<u>Pitches, Laps and Gauge</u> - The angle at which a slate roof should be laid varies with the height, being one-fifth of the span to one-third. The best form under Indian conditions is one third or having an inclination of roof to horizon = 33° ~~degrees~~ 42′ ~~minutes~~; but this may be increased to 45°, where it is intended to show up the roof from a distance. Lap should not be less than 3". In a slate of 20"x10" size and the nail put in at one inch from the edge the "lap" being 3" the 'gauge' is :-

$$\frac{19 - 3}{2} = \frac{16}{2} = 8''$$

The above refers to slates nailed at the edge; the better course, but one which is seldom adopted, is to put the nails in or near the centre, then the 'gauge' is equal to half the difference between the "lap" and the full length of the slates, thus in the above case the "gauge" would be :-

$$\frac{20 - 3}{2} = \frac{17}{2} = 8\frac{1}{2}$$

To know the "gauge" is of great importance, as it fixes the distance apart at which the battens carrying the slates should be placed.

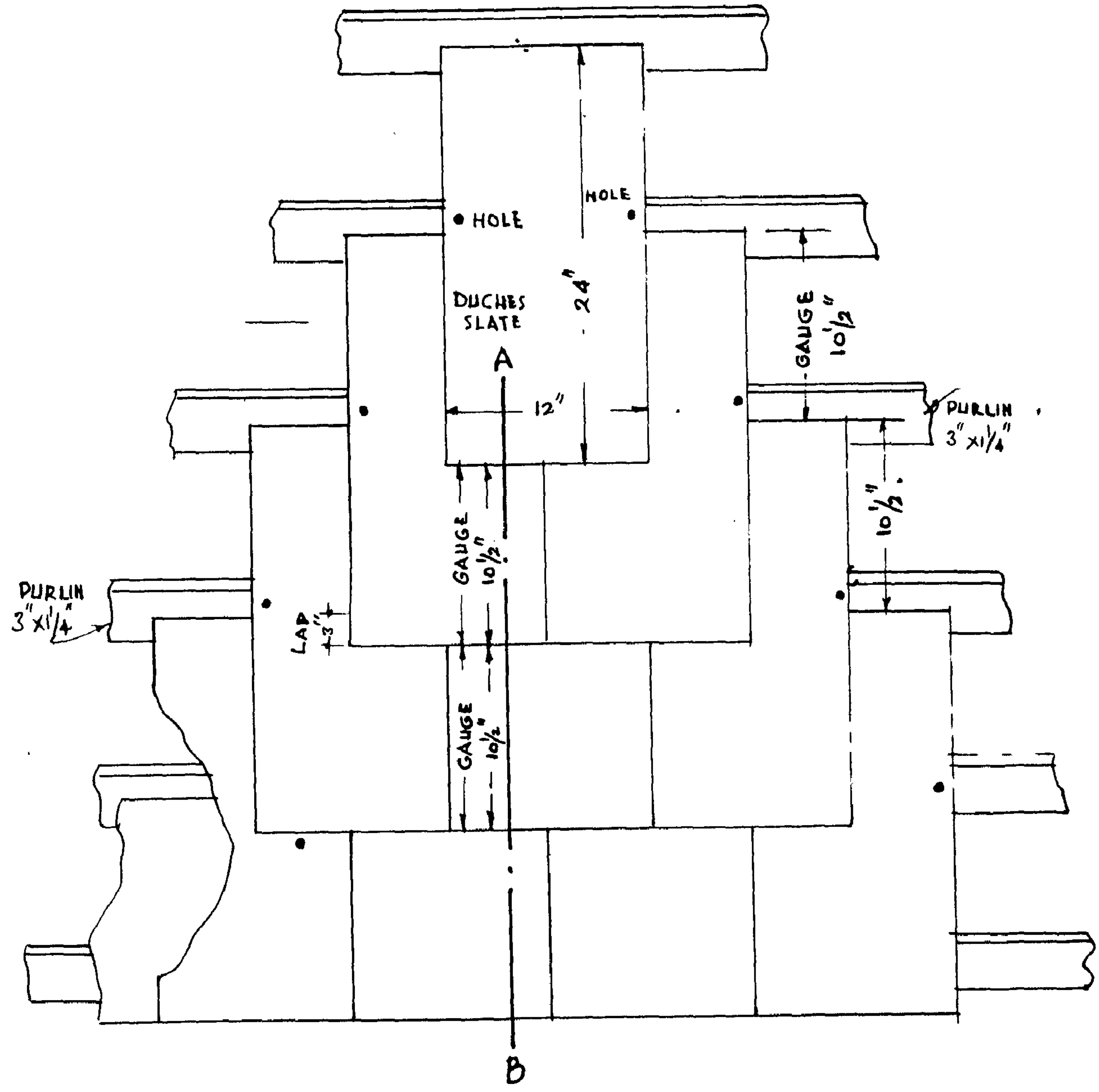
Nailing - As regards nailing the slates, the best method is to nail these in the centre. It is preferable especially in large slates, as from the position of nails the wind acts upon the slates with a leverage of only about half their length. Moreover the slating so laid is easier to repair or for replacement; the only objection being that the nail is put in the second slate, and the breakage of the top slate exposes the nail head; where as in nailing on the upper edge, the first or lowest slate is nailed, and it would require two layers of slate to be broken before their nail head would be exposed. Slates, however, seldom break unless disturbed by wind.

Placing - Having got the size of "lap" and "gauge" fixed, the slates should be drawn or marked on the slope, and the position of the holes fixed; then have a template made according to which the holes are drilled. This is done best by a proper "slating tool" but can also be done by an ordinary steel punch. All slates should be laid with the smooth side down, and the bevel edges turned up, except the first row at the bottom of the slope where the two bevels of the slates meet at the lower edge (Fig.40) The first row has to be of a length different f from other rows, and is equal to "gauge" , plus "lap" and it must also be tilted up with a "tilting piece" of wood so as to make the rest of the pieces sit flat on one another.

Great care should be taken in making the horizontal edges of the slates prefectly straight, so as to have the vertical joints also in a line intersecting the slates below exactly in the centre.

It may be observed from figures 41 & 42 that at the "lap" the nail just clears the edge of the lowest slate, and that at this point there are always three layers of slates one over another. For economy slate roofing is often made with no planking underneath; but simply on bottoms as in figures 41 & 43, when the space between battens is equal to the gauge of the slate.

Roofing Felt - In the plains, owing to the heat, planking may be put below the slates to act as a non-conductor; and further to keep out both heat and rain, it is best to put down a layer of tarred felt. In laying slates over planking and felt, the purlins underneath may be 3 to 4 ft. apart, and thus save timber, while light battens would have to be nailed over the felt, at a distance apart of the "gange", as in figure 42.



PLAN

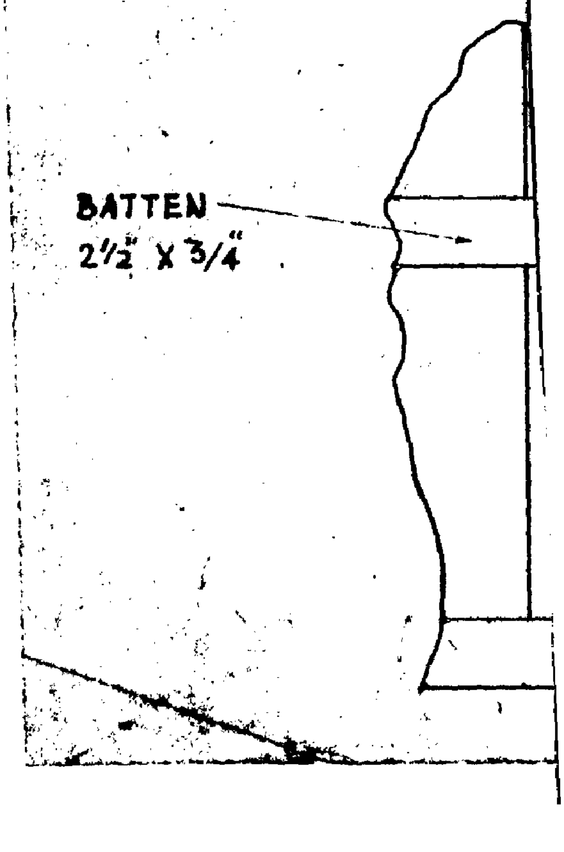
SCALE:- 3/32" = 1'

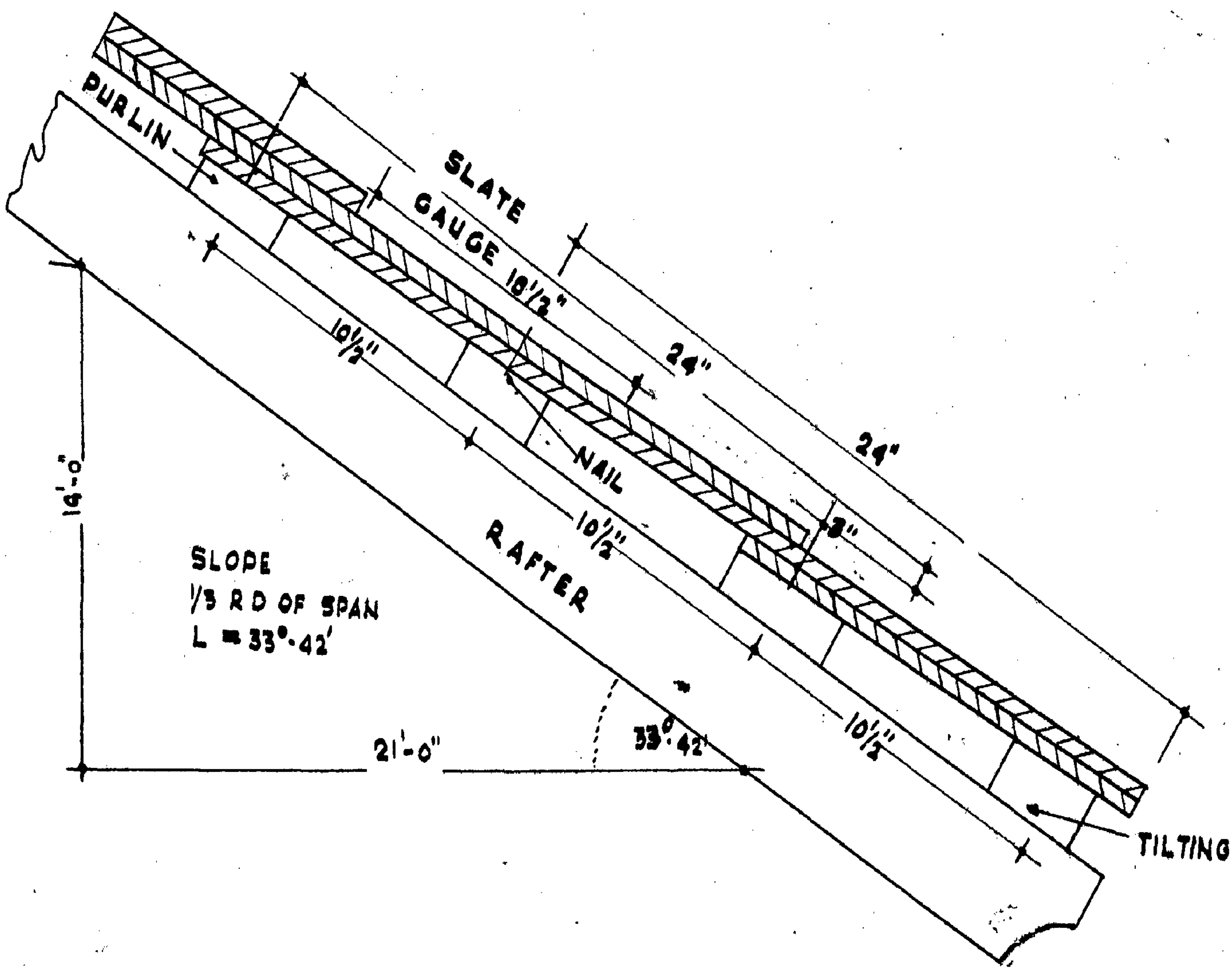
DETAILS SHOWING METHOD OF FIXING SLATES

FIG. 40 A

DETAILS SHOWING
FIXING SLA

FIG. 40





SECTION ON A.B. (FIG.40.)

FIG. 41

Slates can be used on iron roofs trusses euqually well as on the wooden types. (Fig.43), and would form a far cooler and better roof for the plains than corrugated iron sheets.

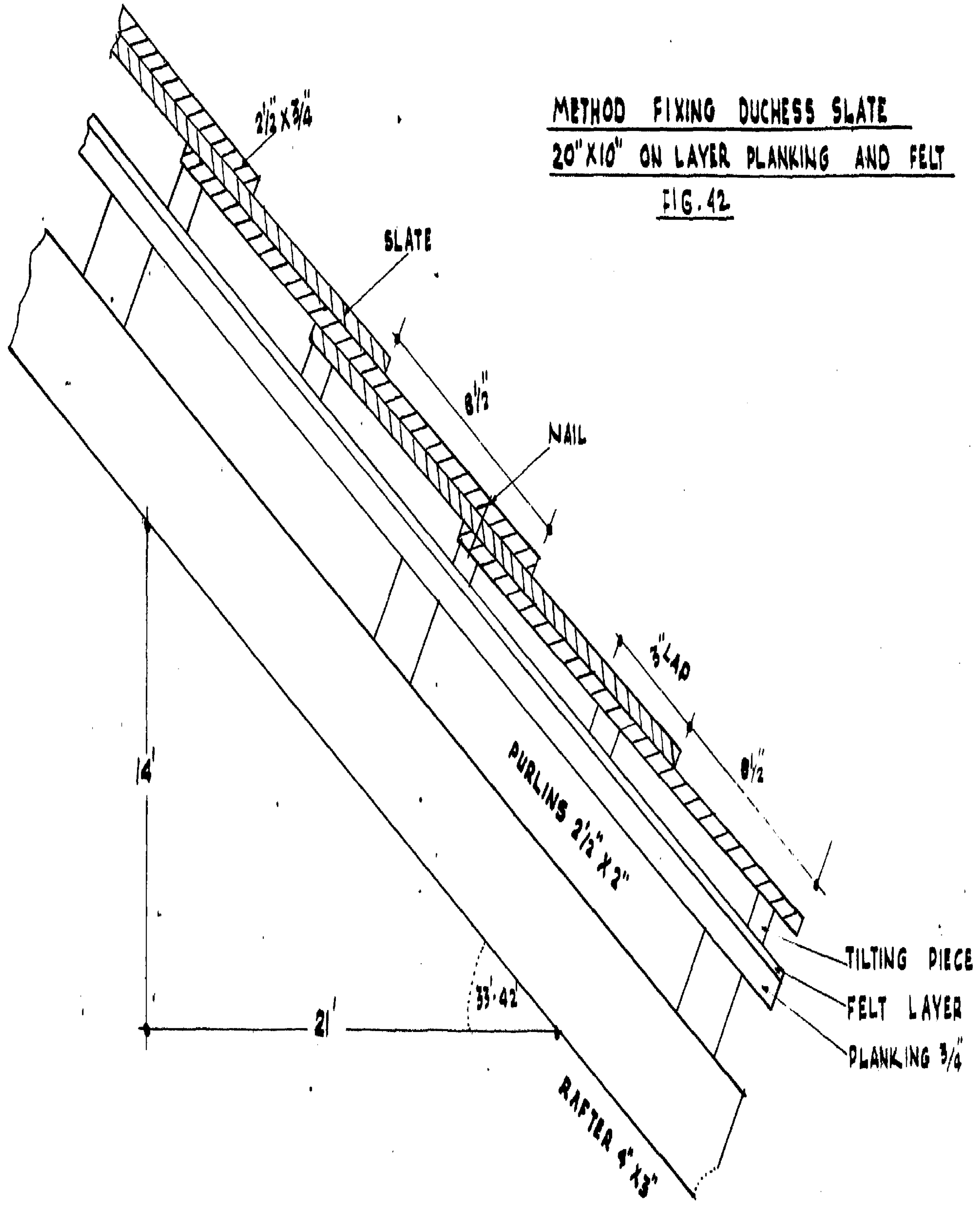
Hips and Ridges - The ridging and the hip joints of slate roofing should be covered with sheet iron or sinc roll, as in Figures 44 & 45, and the ridging may be finished off with a cresting and painted black or slate colour. The best practice is to form a cement concrete roll (ratio 1:2:4) about 3" in diameter on an apex formed by the edge of the slate.

Dips and Valleys - In dips and valleys slates must be cut obliquely to fit the angles, and the depression in the valley must be covered with a layer of sheet lead or galvanised sheet under the slates to carry off the rain water.

Flashing - Where vertical walls abut against the roof or chimneys go through the roof, "flashing" the joints or intersections with sheet lead has to be carried out. The method of flashing the intersections is to be have two sheets of lead overlap one over the other as in Fig. 46, and each place requires its own detailed pattern of carrying this out, the principal being the same.

METHOD FIXING DUCHESS SLATE 20"X10" ON LAYER PLANKING AND FELT

FIG. 42



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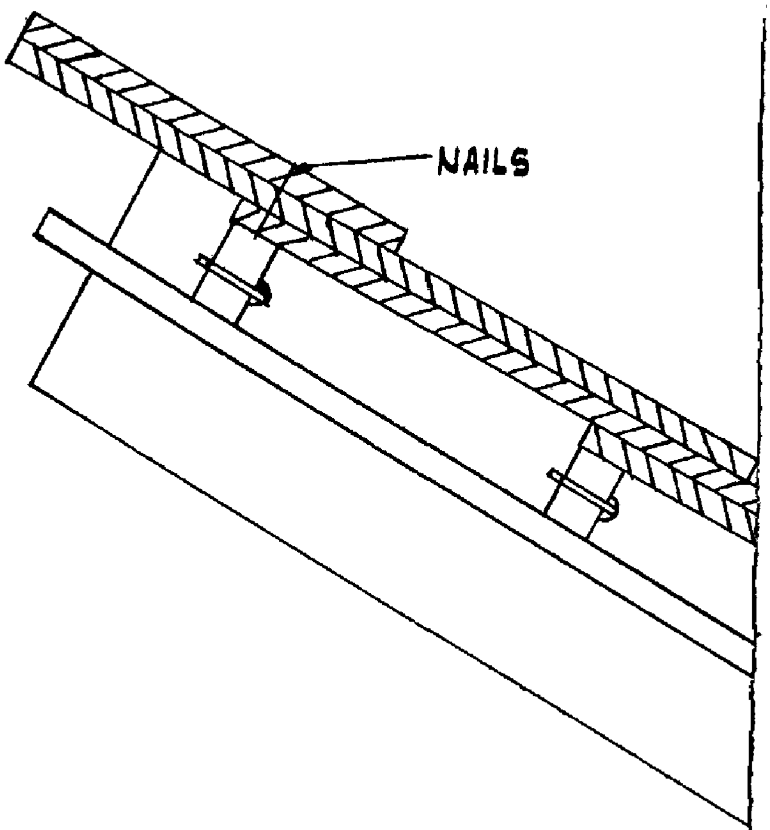
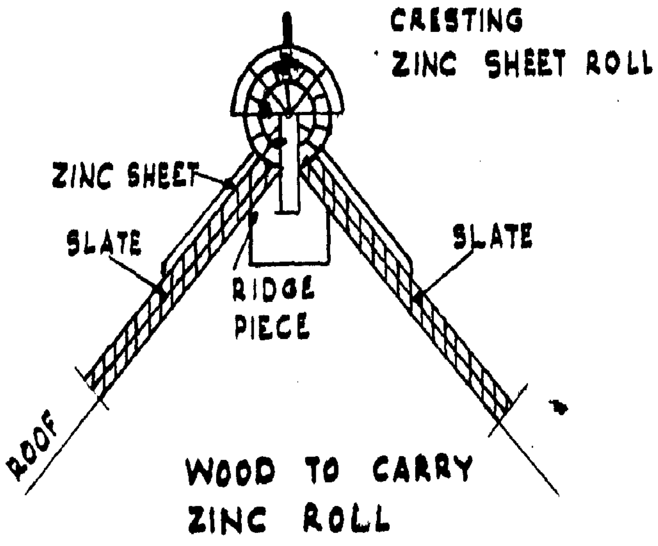
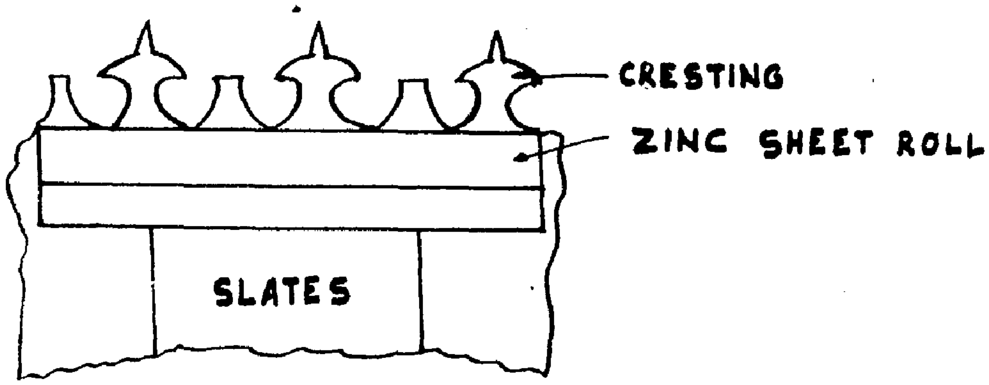


FIG. 4

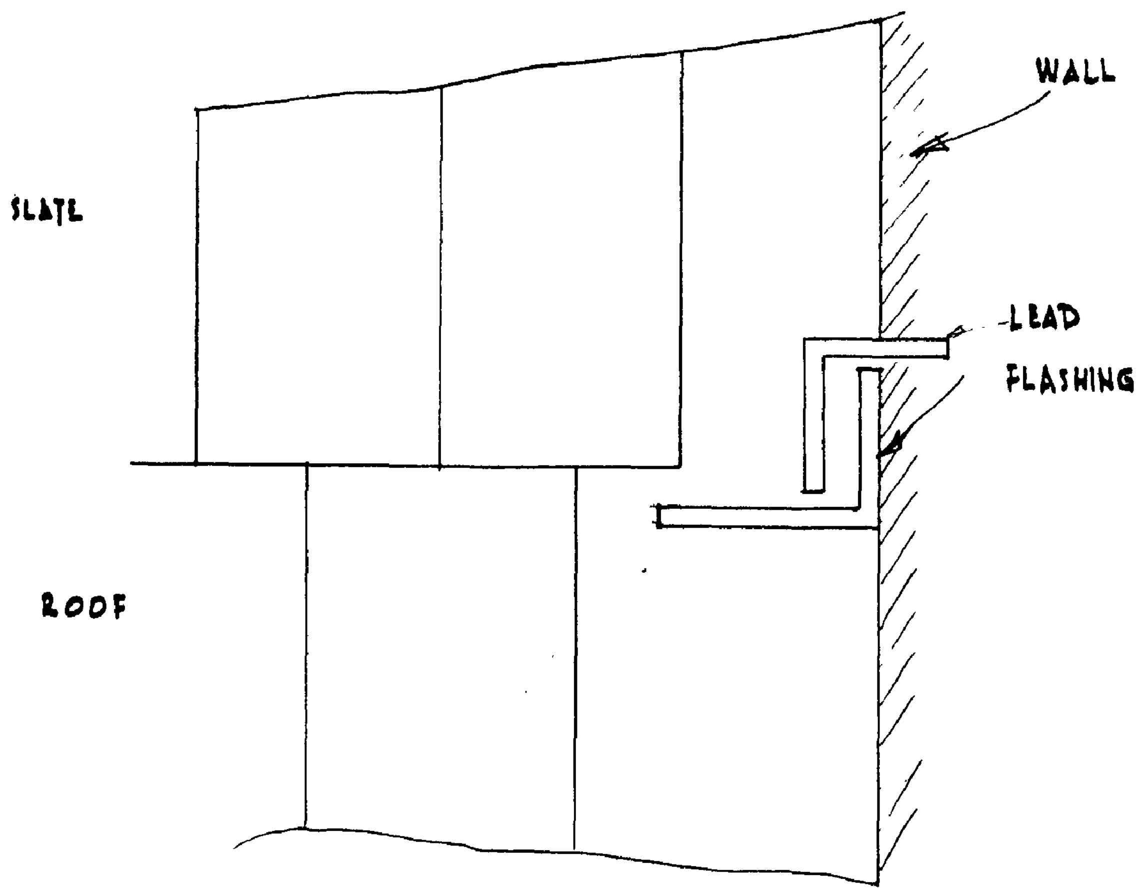


WOOD TO CARRY ZINC ROLL IN SLATE ROOFS

FIG. 44.



CRESTING
FIG. 45



FLASHING IN SLATE ROOFS

FIG. 46

PART II.

ROCK AGGREGATES

CHAPTER XI.

INFLUENCE OF PETROGRAPHIC AND MINERALOGIC PROPERTIES ON AGGREGATE FOR QUALITY CONTROL OF CONCRETE

Rock itself is a natural concrete and when mixed in the form of aggregate with cement paste forms more than 2/3 of artificial concrete. This suggests that any satisfactory understanding of concrete requires some insight into the properties of rocks used as aggregate.

Until recently the engineer considered all aggregates as inert materials and employed the one on which he could lay his hands readily and economically. Since the recent past, the position is changed and the quality control in concrete has come into prominence, particularly in the large and heavy engineering constructions. In such a control the first factor is the quality of aggregate. The chief factors of variations in the aggregate are the mineralogic and the petrographic properties of mother rocks and these produce concretes with wide difference in strength and durability. From this it is, therefore, evident that the first question the engineer puts is "How will this rock act as an aggregate?" Is it physically and chemically sound? And such other questions confronts the engineer before he finally decides in favour of a particular aggregate.

On the other hand the properties of rocks and minerals for concrete mixtures appear to be different from those generally familiar to the geologists and petrographers - i.e. the crushing strength, toughness etc. which are the reflections of the textures grain size, structure and mode of formation of rocks. From this it seems that the evaluation of certain petrographic features of the rocks is an essential aspect. Few rocks are excellent on all counts, though many relatively poor in quality in certain respects may be strong in others. Rocks with poor and better factors are to be balanced against each other and assessed accordingly. It is this aspects of the rocks and their descriptions that are dealt in this chapter.

During his studies on the geochemistry of rocks Clarke[79] made a statistical estimation of some 700 igneous rock types and that led to the following rough estimation of their mean mineralogic composition.

	Quartz -	12.0%
	Felspars -	59.5%
Feromagnesium-minerals.	(Hornblende) (Pyroxenes)	16.8%
	Mica -	3.8%
	Acc. Minerals	7.9%

With a view to find out the influence of the above rock forming minerals on the ultimate strength of concrete, briquettes of concrete were made with various minerals as aggregate in 1:4 ratio by volume (p.67&68). Before testing the briquettes were stored in dampness for 48 hours, and some stored for 24 hours and these autoclaved at 150°C for 24 hours. Results of tests on strengths have been given in the following table No. 77.

Tensile strengths in p.s.i. of concrete briquettes made with various rock forming minerals (1:4 by volume).

(Table on Page 190)

Name of Mineral	Stored in dampness for 48 hours.	Stored in dampness for 24 hrs. Autoclaved at 150°C 24 hrs.	In water 6 months
Quartz (SiO_2)	84	520	340
Chert (SiO_2)	96	780	560
Flint (SiO_2)	90	710	425
Quartzite (SiO_2)	86	735	400
Microcline ($KAlSi_3O_8$)	85	104	450
Albite (Ab) $NaAlSi_3O_8$	78	165	438
Orthoclase (Ab_4 An_1)	60	210	430
Anorthoclase $(Na, K)\ Al\ SiO_3O_8$	80	150	320
Labrodorite (Ab, An)	105	220	415
Hematite ($FerO_3$)	110	205	535
Magnesite (MgCo3)	125	575	685

Table No.77.

From the results given in Table No.77, it can be seen that the quartz which is the most common rock forming mineral and occurs in a crystalline form gave concrete having a tensile strength of nearly 340 p.s.i. after six months of water curing. Briquettes autoclaved at 150°C for 24 hours gave 520 p.s.i. nearly. On the other hand, other forms of silica which include flint, chert and chalcedony give much higher strengths than quartz under different conditions of curing. This is perhaps attributable to a higher percentage of free silica bonds in the latter varieties.

Felspars include a group of minerals occuring in most igneous rocks as orthoclase, microcline, albite and the plagioclase felspars of the sodalime (albite - anorthite) series. It has been observed from the results given in table 77 that the strength of concrete in which felspars alone have been used is high and sometimes more than the concrete made with quartz. It is interesting to note from the results (Table 77) that (on steam curing) the strength of concrete made from felspars has been generally reduced on steam curing. It has been observed that the higher the percentage of alkalies in a felspar the lesser the strength obtained by autoclaving the concrete. Further, its has also been noted that the effect of 'Potassium ions' is greater than 'Sodium ions', on the strength reduction of concrete on antoclaving.

From the point of view of a concrete engineer, another important point is that the amount and the mode of distribution of the decomposed product in a rock should be minimum. According to Knight[80] the best quality igneous rocks for concrete should not have a decomposition percentage of more than 15%. Significant factor about felspars is that they have a strong tendency to occur in a decomposed state in rocks. Obviously the degree of decomPosition and its distribution within the felspar-crystal must influence the strength of the aggregate in which they occur. Regarding the distribution of weathered portions, sometimes the centre portion of the felspar crystals is cloudy and the border is clear (Pl.51 Fig.1). Such a weathering is commonly met in Bhulvan granites. This is likely to cause less significant lowering of strength in concrete than border decomposition or cloudiness which is evenly distributed throughout the whole mass

PLATE No.51 Fig.1

PHOTOMICROGRAPH OF FELSPAR CRYSTAL SHOWING WEATHERED PORTION IN CENTRE W = Weathered Portion X 120.

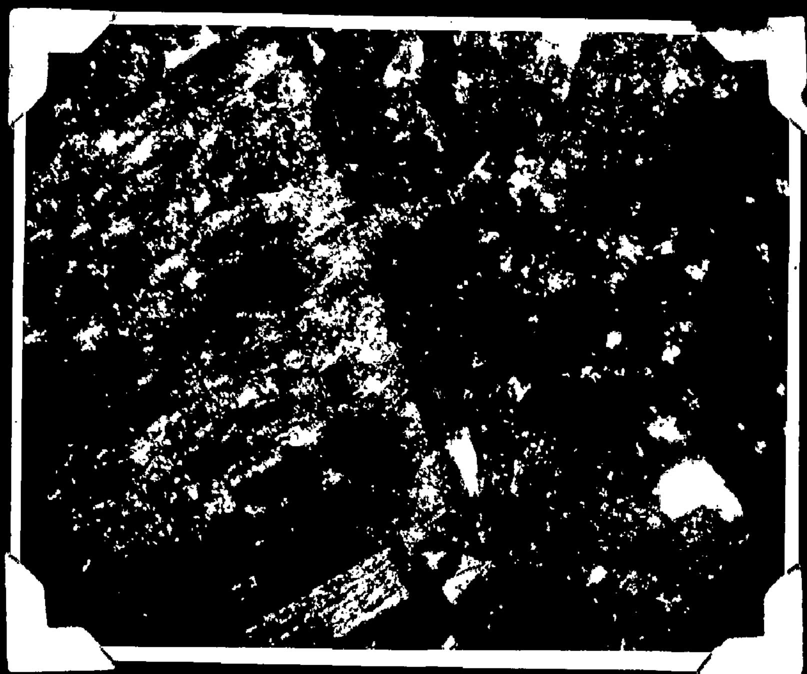


PLATE No.51 Fig.2

PHOTOMICROGRAPH OF FELSPAR SHOWING CLOUDINESS EVENLY [illegible]

Out of the ferromagnesium minerals including the amphi-boles, pyroxenes and the micas, the amphiboles are tough minerals and tend to offer this toughness on rocks, such as Bangalore Granites, in which they form an appreciable part, except when these are badly decomposed. Like amphiboles, fresh pyroxenes also tend to confer toughness on rocks partly by virtue of their toughness and partly owing to their mode of crystallization which gives good structural strength to the rock and this has been observed in case of Deccan trap basalts and dolerites (Page 151 & 153). Mica due to its soft and flaky nature is supposed to be a harmful impurity when present in large quantities. It is considered detrimental to the strength and durability of the concrete. The smooth surface of mica allows only a poor bond for the cement paste. As stated by Knight[80] mineral olivine is not harmful to the strength of the aggregates except when it exists to such an extent that it makes up almost the whole rock, in which case the rock behaves brittle. Accessory minerals like apatite, zircon, rutile, sphene etc. of the igneous rocks do not affect the concrete making properties of rocks in which they are found.

PERCENTAGE OF MINERALS IN ROCKS FOR AGGREGATE

According to Knight[81] while discussing the importance of different minerals from the quantitative point of view in concrete masses, gave that the best results in hard-wearing concretes are obtained by having nearly 25% quartz, 65% felspars and micas not more than 10%. For such a concrete, augite and hornblende, because of their brittle nature, should preferabley be absent or be present in very small amounts. Further he concluded that the most satisfactory igneous rock for use in concrete should have a mineralogic composition as follows :-

Quartz	-	25%
Felspar	-	40%
Augite or Hornblende		20%
Mica	-	10% or less
Other minerals	-	5%

GRAIN SIZE

The average grain size that has been found best by Knight[82] for quality aggregate and for the most abundant mineral such as felspar and quartz is about 0.8 mm., the upper limit being 2.3 mm and the lower 0.4 mm. If the upper limit is exceeded the aggregate possesses high attrition and low impact values, whilst if a finer grain size, averaging less than 0.4 mm. is used, the rock though hard is brittle.

HARDNESS.

It has been observed here that according to Moh's mineralogical scale[83] hardness is designated by values ranging from 1 to 10, based upon the comparative ease with which the minerals are scratched. This does not give an idea of the amount of alteration or weathering which a particular mineral grain has under gone. Such as, a fresh felspar has a hardness of the order of 'Six' according to the Moh's scale and is quite strong from aggregate point of view. On weathering the same mineral grain become soft and weak. Similarly a soft minerals like calcite etc.

may also weather and produce weak particles. Hence, a distinction can be made here between 'WEAK PARTICLES' and 'SOFT PARTICLES' A weak particle is produced as a decomposed product of either a hard or a soft mineral, whereas a soft particle is that which yields to abrasion and attrition. However, from the point of view of an abrasion resistant concrete both 'Weak' and 'Soft' particles in an aggregate should be minimum. On the other hand, soft mineral particles are not necessarily harmful in a high tensile strength concrete, provided they afford good bond and molecular cohesion.

INTERNAL TEXTURE AND STRUCTURE.

The internal texture originates by the solidification of the magma in case of igneous rocks, by the cementation or consolidation in sedimentary deposits and by recrystallization in metamorphic rocks. In coarse granites where the mineral quartz lies in contact with the relatively smooth surfaces of the early formed crystals of felspars and amphiboles (Pl.52 Fig.1) low strength can be expected. Less siliceous crystalline igneous rocks such as gabbro and diabases are composed of crystals which have formed more or less simultaneously and consequently the boundaries are well interlocked (Pl.52 Fig.2). In such case strength in an aggregate is supposed to be appreciable. The Granopyric texture which is a result of the simultaneous crystallisation of quartz and felspars indicate a strong key between the two minerals and is obviously a great advantage for making it a high quality aggregate. Ophitic texture of dolerites where large crystals of augite enclose felspar lathes, account for a good aggregate making property. The value of

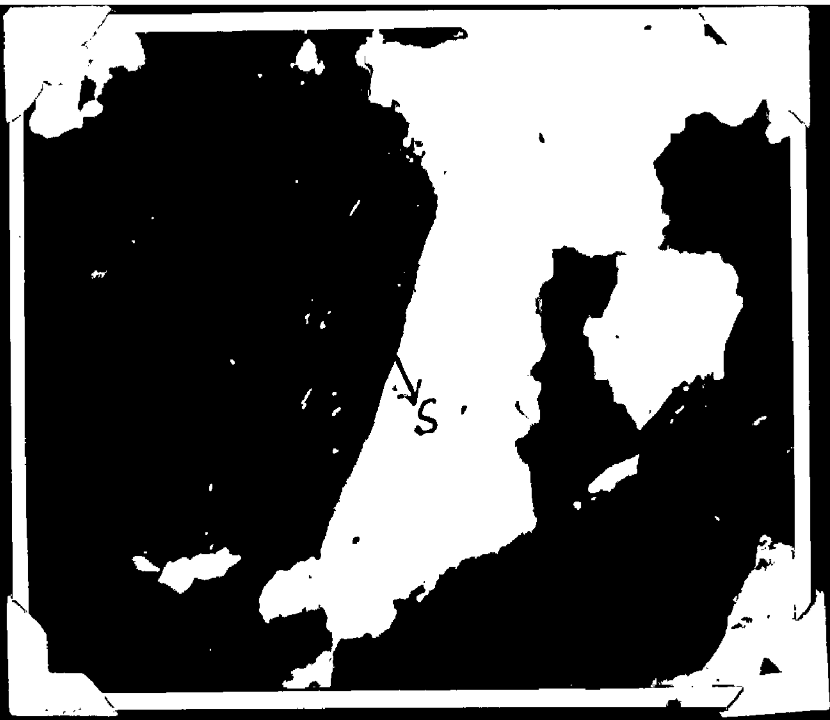


PLATE No.52 Fig.1

PHOTOMICROGRAPH OF COARSE GRAINITE SHOWING MINERAL QUARTZ IN CONTACT WITH SMOOTH SURFACE OF FELSPAR.
(S = Smooth Surface).

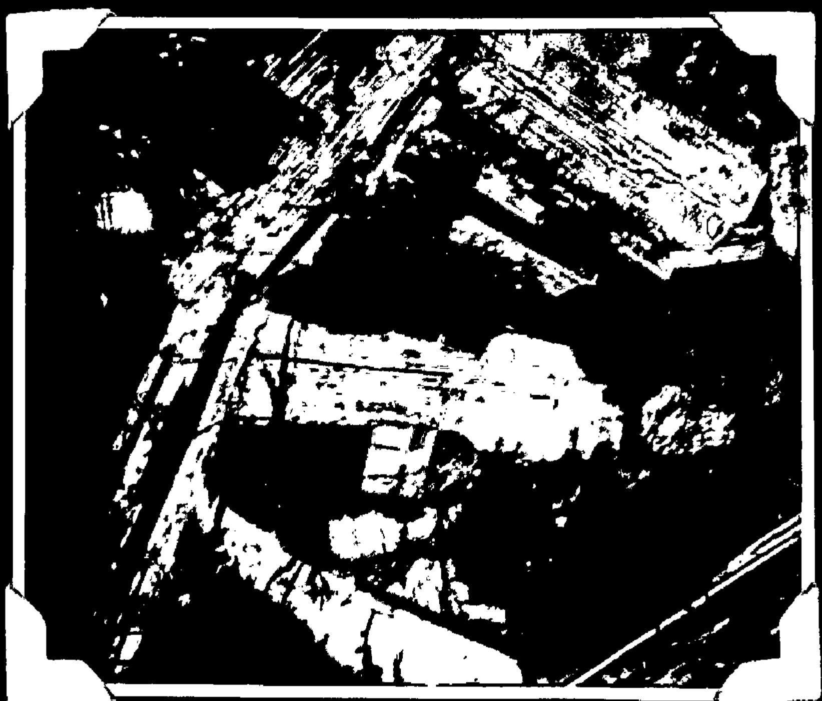


PLATE No.52 Fig.2

PHOTOMICROGRAPH OF GABBRO SHOWING INTERLOCKED BOUNDARIES
X 60.

this texture is greatest when felspar laths, in considerable number, penetrate the adjacent augite crystals so that the interlocking is perfect. As can be observed from the results given in table No. 77 crystalline quartz has given lower values as compared to other forms of silica like Flint and chert etc. Volcanic rocks like rhyolites, tuffs etc. usually contain some natural glass. This besides making the whole mass more brittle affords a very poor bond between the cement and the aggregate. Obviously the molecular cohesion as a source of strength development (P. 167) is not fully developed between cement particles and the aggregates particles.

In sedimentary rocks, particularly in the quartzose varieties the interlocking of the constituent mineral particles can only depend on the shape of the grains. Grains may be angular, subangular, rounded or sutured (Pl.53) . The nature of the cementing material in sedimentary rocks is also of great importance. Ferrugenous, micaceous or chloritic cements such as found in Upper Bhander and Gondwana Sandstones indicate a low quality material (P.167).

In the metamorphic rocks the nature and quality of the aggregate is dependent on the nature of the original composition of the rock from which these are derived under conditions of high temperature, high pressure, and high shearing stresses. Quartzites from Alwar or Delhi formedunder dynamothermal conditions developed a granular texture and a m ssive internal structure, characterized by great strength and toughness. This is due to the firmly knit and well interlocked grain boundaries (P.157). Rocks formed under dynamic metamorphism develops the

PLATE No.53

PHOTOMICROGRAPH OF SANDSTONE SHOWING SATURED GRAINS.
(GRAINS HAVE BEEN SEPERATED MECHANICALLY)
X 80.

foliated structures such as in slates, phyllites, schists and gneisses (Pl.37, 38, 39). Such rocks are made up essentially of zones containing oreinted flaky or prismatic minerals and bedding planes due to which they break easily along these structural planes. These rocks are so poor that it is not even worth submitting them to tests usually carried out on aggregates.

Further, the shape of the broken aggregate which is important from the workability and compaction point of view of concrete, is closely dependent upon the internal texture and structure of the parent rock. Spacing of natural partings and cleavages in the rocks play a profound influence on the final shape of a broken aggregate. Sometimes rocks contain planes of parting or jointing which are formed in response to the stresses during the transformation or due to the internal petrographic structures of the rocks. As a consequence schists, slates and shales produce flaggy forms (Pl.54 Fig.1) whereas pebbles of granites, marble and quartzite are usually equi-dimensional (Pl.54 Fig.2). Similarly quartz with no ready cleavage yields equidimensional sand grains. The two cleavages of felspars cause development of tabular and rectilinear forms. Fine grained massive rocks such as many cherts and quartzites produce an aggregate that is hard, with many shell like chips.

ELASTICITY AND STRENGTH.

La Rue[84] who carried out tests on the modulus of elasticity of aggregates and their effect on concrete, concluded that the aggregates produce a decided effect on the elastic properties of concrete. Stone having a high modulus of elasticity developing correspondingly higher module in the concrete than stone having

PLATE No.54 Fig.1

SURFACE PHOTOGRAPH OF SLATE PEBBLES SHOWING FLAGGY FORMS.

PLATE No.54 Fig.2

SURFACE PHOTOGRAPH OF MARBLE PEBBLES SHOWING EQUI-DIMENSIONAL SIZE.

lower moduli. Further the significance of elasticity and strength of the coarse aggregates can be judged from the fact that it occupies a volume of approx. 43% in concrete. Results of compressive strengths and dynamic modulus of elasticity of Indian rocks are given in chapter VI and VII.

ROCKS AND THEIR CHEMICAL STABILITY IN CONCRETE.

It has been customary to consider the aggregate as an inert material in concrete. However, it is not always the case and certain aggregates are either chemically unstable or react with cement when incorporated in concrete.

The chemical reactions may be beneficial or deleterious depending upon the nature of the reactions. The reactions that increase the bond between the aggregate and the matrix are beneficial, while those that cause abnormal expansion and consequent map cracking are deleterious. There is no suitable direct test to evaluate the beneficial reactions, hence these are not mentioned here. From the point of view of chemical reactivity the rocks are classified into two groups :

1. Chemical Reactions Independent of Cement.
2. Chemical Reactions Between a Cement component and some Mineral in the Rock Aggregate.

In the above mentioned classification some over-lapping is unavoidable since certain minerals may possess more than one harmful property.

CHEMICAL REACTIONS INDEPENDENT OF CEMENT

(1) Oxidation, hydration and carbonation.

In warm and humid climate, so common in India, these processes lead to popouts and surface staining of concrete. Minerals such as pyrite and marcasite undergo oxidation and hydration to form dilute sulphuric acid and hydrated iron odixes. Such minerals are not revealed by the standard tests and can be identified only through petrographic methods. The ~~present~~ magnesia, in aggregates sometimes become carbonated with large increase in volume.

(2) Soluble Minerals and Clay fractions.

Few minerals are sufficiently soluble and their presence in the water content of the cement paste affects the quality of concrete through salt reaction with a cement component or by changing the composition of the paste solution itself.

Gypsum and certain clay fractions like Kaoline in Upper Gondwana sandstones and in some other sedimentaries are the most common impurities. The soluble constituents may be leached out leaving a porous mass behind.

CHEMICAL REACTIONS WITH CEMENT.

The chemical reactivity in general and the cement aggregate reactivity in particular, have become synonyms and are called as the alkali-aggregate reaction by many concrete engineers. The reaction between the alkali present in cement, and the reactive constituents in rock aggregates is one of the most important reaction out of other known harmful chemical reactions, involving aggregate in concrete, such as 'Base Exchange Capacity of certain minerals.

(1) Base Exchange.

According to Swenson and Chaly[85] certain Zeolite minerals and adsorptive clays are subject to base exchange by adsorption of certain cation from solution and simultaneous release of other cations. For example, a diorite rock containing a zeolite will adsorp calcium ions from the cement paste solution and replaces Na or Kions originally present in these rocks. Consequently the composition of the solution permeating the cement pasto is changed and affects the setting and hardening of the concrete. The resulting increase in the alkali content in the paste solution appears to be one of the causes of excessive efflorescence. By tho increase in alkali content in the paste, reaction with alkali-reactive rock aggregates, may also be promoted.

(2) Alkali Aggregate reaction in Concrete.

Beginning with the work by Stanton[86] in 1940 and followed by that of a number of other investigators[87 to 97], a good deal of information is already available on the subject both on the thooretical as well as practical aspects. A number of methods of tests[98,99] for potential alkali - roactive aggrogates have been evolved.

The mechanism by which the chemical reaction between particles of aggregate and alkalies of cement are converted into expansion of tho mortar or concrete has been interpreted in many ways[100]. As a result of early studies, Stanton[101 tp 103] suggested that the expansion resulted from attack of alkalies upon rocks containing magnesium carbonate, but later observations by others[104 to 109] indicated the disruptive effects to be at least spatially related to secondary alkalic silica gel produced by the chemical reactions between cement alkalies and contain siliceous aggregates. Hansen[110] suggested that the expansion and deterioration are effected by osmotic pressures within these gels.

In India the concrete era has started only very recently. Regarding failures, in concrete, they do take place but it is very difficult to attribute them to a definite cause, because the concrete making specifications are not followed strictly and there is a great variation in the mix. designs and the cement composition etc. Under these circumstances, to assign the cause of a failure becomes rather difficult. However, examples of the failure of great important structures in U.K., U.S.A. and other Overseas countries have helped to alarm the engineers of this country also.

To study the phenomena of alkali-aggregate reaction in laboratory, experiments were conducted during the present study. Opal and Chalcedony were used as aggregates with high alkali cement (P.69) and the cubes were prepared and kept in water for six months. Later on these cubes were examined under reflected light by the help of 'Ultropek'. The formation of silica gels could be detected at several places (Pl.55).

It is well known that almost all silicates and silica minerals react with the alkalies present in the portland cement,

PLATE No.55

THE FORMATION OF SILICA-GEL IN ALKALI AGGREGATE REACTION x 120.

but the greater number of other minerals react only to an insignificant extent. For example, felspars, pyroxenes, amphiboles, zeolites, micas, quartz and other rock forming minerals cause insignificant expansion.. Opal is considered the most highly reactive material. Similarly cryptocrystalline and glassy volcanic rocks must be considered highly reactive when used with high alkali-cements. Basalts are to be considered innocuous under ordinary conditions. The rocks and minerals which have been found to be deleteriously reactive with high alkali cements are given in the following tables No. 78 and 79.

ALKALI AGGREGATE - REACTIVE MINERALS

Name	Composition	Crystalline Character
Opal	SiO_2 H_2O	Amorphous
Chalcedony	SiO_2	Crypto-crystalline Fibrous
Tridymite	SiO_2	Crystalline.

TABLE 78.

ALKALI AGGREGATE - REACTIVE ROCKS

Name	Reactive Constituents
Sedimentary Rocks	
Opaline Cherts	Opal
Chalcedony cherts	Chalcedony
Siliceous limestones	Chalcedony and/or Opal
Volcanic Rocks	
Rhyolites and rhyolite tuffs	Volcanic Silica
Dacite - Dacite tuffs	Volcanic Glass, devitrified glass.

Andesite - andesite tuffs	Tridymite
Metamorphic Rocks	
Phyllites	Hydromica ?

TABLE 79.

A FEW UNKNOWN CHEMICAL REACTIONS BETWEEN ROCK AGGREGATES & CEMENT

The study of physico-chemical phenomena of hydration of cements and of the setting and hrdening of concrete is still incomplete. Various analytical methods including petrographic and metallographic microscopy, X-ray diffraction methods and more recently electron microscopy have been applied to problems of cement hydration. Still the chemical reactivity of rocks and minerals used as an aggregate is not fully understood and recently number of examples have come to light where the actual cause of the reactions involved have not yet been established. A few important instances have been quoted below :- are/

(1) In December 1957 an interesting example was brought to the notice when Swenson[111] found a Canadain reactive aggregate of dolomitic limestone which remained undetected by ASTM tests. This was a case of an unusual cement aggregate reaction for which the standard tests were neither effective nor proved of any help. In the words of Swenson :

"Petrographic examination of specimens of both laboratory and field concretes which had expanded excessively revealed unmistakable evidence of cement-aggregate reaction involving the crushed limestone particles, may of which exhibited darkened reaction rims. The exact nature of the reaction and the constituents actually responsible were not detected. The absence of significant amounts of gel deposits was considered significant. Petrographic examination of the dolomitic limestone revealed that that the constituent could be regarded as not normally reactive with high alkali cements. Physically this material was considered satisfactory".

(2) A case of excessive shrinkage of natural stone and sand aggregates has been reported for the first time by Stutterheim[112] In 1950 at Grraft Reinet in South Africa a commercial building which had just been completed, developed some cracks and the trouble started with strong room doors. Shortly after those cracks were observed in beams, slabs and columns, as well as in brick panels. The cracking was first evident on the first floor of the building, but later spread to the ground floor and basement. Similar incidents were later on noticed in a college hostel at Graaff. The beams which spanned 30 ft. each had saggered by about 1½ inches at the mid span. The openings at some places became 3/4 inch wide.

On examination it was found that the Graaff Reinet aggregates contained no reactive silica, and therefore expansion due to alkali-aggregate reaction proved false in this case. Examination of concrete failed to reveal the presence of sulphates also in sufficient quantities to have any significant effect on the material. According to Sttutterheim, the critical consideration of the symptoms of failures led to the conclusion that they could not all be explained on the basis of an expansion.

Since volume change was so obviously a cause of the trouble, the possibility that shrinkage was the root cause was studied and it was deducted that this could provide an explanation of all features observed.

It was observed that during moist curing, shrinkage of concrete, where these aggregates were used, was from 2 to 5 times as great as that of normal concrete. Air drying of concrete brought about slow increase in shrinkage and on oven drying, it led to excessively large shrinkages, occasionally exceeding 0.1% (which is about 10 times that for normal concretes of these mix designs).

With a view to examine the aggregate and to find out if such rocks are present in India, the two specimens from 'Municipal Quarry', 'Adendorp Quarry' of Africa were obtained and thin sections of these rocks were studied under the microscope. The stones are composed of quartz and felspar grains cemented together in a microcrystalline micaceous matrix. Though the matrix could not be resolved further even under a magnification of about 1400 times, it appears that some clay minerals are present, because the whole stone has a mud stone type of appearance (Pl.56) X-ray analysis confirmed the above idea and showed the presence of Kaolin, sericite, illite and montmorillonite.

Since it was a case of excessive shrinkage of the rock as reported by Stutterhein,[112] the shrinkage percentages have been obtained by preparing stone bars of 6"x2"x2" size and subjecting them to cycles of wetting under distilled water and drying in oven at 105°C. As can be seen from the table No.80 given below a progressive increase and decrease has been observed. contd

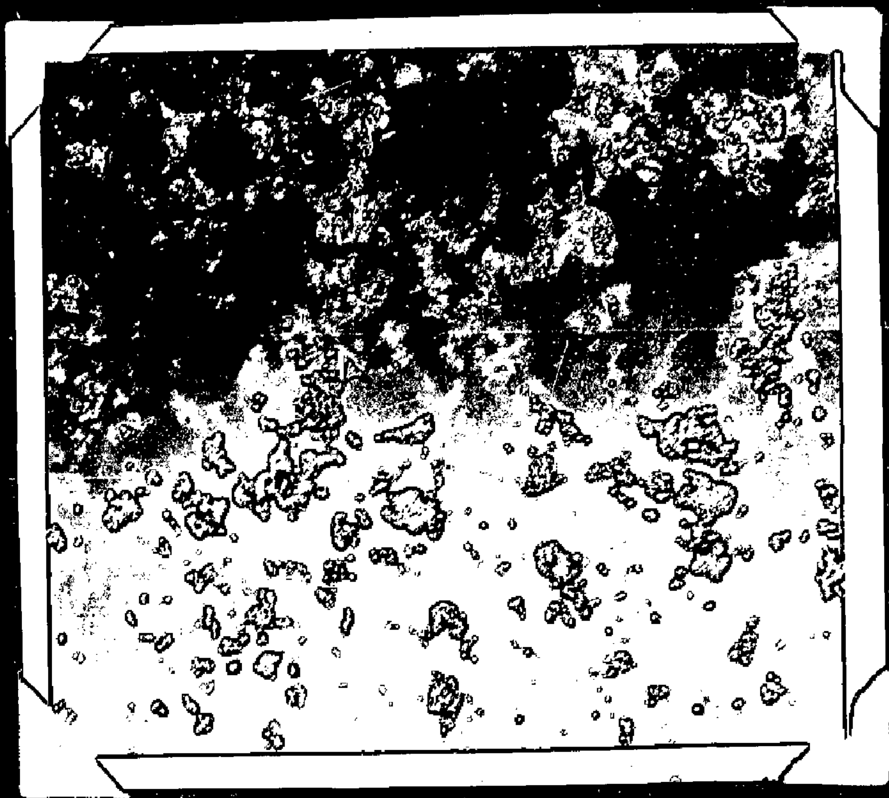


PLATE No.56

PHOTOMICROGRAPH OF MUDSTONE FROM AFRICA X 40.

SHRINKAGE PERCENT OF ROCK AGGREGATES FROM SOUTH AFRICA.

Specimen	Parallel to bedding plane	At right angles to bedding
Graaft Reinet Municipal	0.035	0.055
Adendorp	0.021	0.79

TABLE No.80

However, the experiments are too meagre and still a uncertainty as to whether a clay mineral in the rock is responsible for observed shrinkage or there is any other factor, requires a detailed examination of the problem.

FIRE RESISTANCE PROPERTIES OF ROCK AGGREGATES

It has been observed that all concrete do not behave alike when subjected to intense ~~thx~~ heat and the differences in their behaviour are largely attributable to the aggregates used. Further, it is concluded by Goldbeck[113] that the coarse aggregates play the most vital role in the resistance of concrete to fire. Some aggregates produce serious spalling others none.

The most important properties of mineral constituents of aggregates for fire resistance is the thermal co-efficient of expansion. Griffith[114] has shown that the thermal co-efficient of expansion of silica bearing rocks is directly dependent upon the percentage of silica and the table No.81 has been compiled from his data.

Type of Rock	Average co-efficient of thermal expansion X 10^{-7}	Percent Silica*
Cherts, quartzites	61	94
Sandstones	54	84
Granitoid rocks	43	66
Slates	44	61
Andesites	36	58
Gabbros, basalts, diabases	31	51

(*Calculated from analysis by J.F. Kemp[115])

TABLE No. 81

It is important to note that an aggregate to be used in concrete should have a low thermal coefficient of expansion, so that the surface spalling is reduced to a minimum. The trap rocks for example andesites, dolerites, diabases, basalts and the limestones and dolomites with some exceptions, have a low thermal coefficient. The coarse grained igneous rocks have somewhat higher coefficient of expansion.

An entirely erroneous idea is prevelent that limestone are poor aggregate for fire protection. Experiments have shown that limestones are exceptionally good aggregates for this purpose. They not only generally have low thermal expansion but, when subjected to intense heat, their surface calcines to a porous, burnt lime which has got a high heat insulating value and, therefore, greater resistance to the penetration of heat to the interior of the concrete mass.

CONCLUSIONS

Besides the role of various mineralogic and petrographic properties of minerals and rocks in concrete, the following conclusion are derived from the experiments conducted in this connection :

1) Concrete where quartz alone has been used as an aggregate, has shown lower strength values than that of felspars (Table 77).

2) Other forms of silica minerals like flint and chert give concretes of higher strength as compared to quartz. (Table 77).

3) Strength of concrete where felspars have been used, gets reduced an autoclaving and the effect of 'K' ions is more than 'Na' ions. (Table 77).

4) 'Weak Particles' are to be differentiated from 'Soft Particles'.

5) As a consequence of the natural cleavages in rocks, the shape of aggregates is greatly effected.

6) Perhaps certain clay minerals are responsible in causing excessive shrinkage in rocks of sedimentary nature. This causes ultimate failure in concrete.

In case of the two South African Sandstones shrinkage percentage ranged from .021 to 0.79. (Table 80).

CHAPTER XII.

ROLE OF COARSE ROCK AGGREGATES IN DEVELOPMENT OF STRENGTH IN CONCRETE

As already stated (P.197), coarse aggregate in concrete occupies a volume of approximately 43 percent of the concrete mass. Obviously, aggregates produce a decided effect on the strength of concrete and the influence of its mineralogic and petrographic properties has already been discussed in the preceeding chapter.

Wright[116] has shown that a certain crushed rock aggregate gave concrete of higher tensile strength than a rounded gravel aggregate. Similar effects were noted by Wright and McCubbin[117] in regard to compressive strength. The surface texture, shape, strength, elastic properties and water absorption capacity of the aggregates have all been suggested[118-127] as possible causes of variations in the strength of concrete of the same mix proportions. In this chapter an attempt has been made to evaluate quantitatively the influence of the following factors on the strength development of concrete.

1) Engineering properties of aggregates in concrete
2) Dynamic Modulus of Elasticity of the rock aggregates
3) Shape of aggregates
4) Absorption Percent
5) Surface Texture

In order to study the influence of above mentioned factors concrete specimens were prepared with 10 different aggregates of rocks from different sources and conditions as given in Table No. 14. The fine aggregate in all concrete mixes was standard 'Annore' sand. Each of the 10 coarse rock aggregates was used in preparing concrete of three mix designs as shown in Table No. 82 given below. Further details of experimental producedure have been given in Chapter IV. (Experimental Techniques).

THE THREE MIXES USED FOR THE TEST

Mix	Cement - Rock Aggregate ratio by Weight.	Water - Cement ratio by weight
I	1:3	0.35
II	1:8	0.60
III	1:10	0.85

TABLE No.82

The tensile and compressive strength were tested in accordance with B.S. 1881[128], by preparing concrete beams 4 inch-square and 20 inch long. Beams were tested at 7, 28 and 91 days respectively and the results are given in Table No. 83, 84 and 85.

Mortar beams were also made with the same mix proportion as given in Table No. 82 and the tensile and compressive strengths determined accordingly. Results given in Table No. 86 are the average of tests as three beams.

PROPERTIES OF THE AGGREGATES

Aggregate	SHAPE		STRENGTH		ELASTICITY	PHYSICAL*		
	Av. Flakiness Index.	Angularity No.	Crushing strengh in p.s.i	Tensile Strength in p.s.i.	Dynamic Modulus in p.s.i.	Surface Texture	Absorption %	Specific gravity
Granite (Bangalore)	23	8	48,248	4205	9.9×10^6	8.8	.8	2.78
Basalt (Bhopal)	36	10	45,075	3827	14.91×10^6	7.8	.6	2.80
Quartzite (Delhi)	27	5	28,975	5006	10.7×10^6	6.3	.87	2.75
Sandstone (Dholpur)	28	6	19,261	1986	4.2×10^6	2.5	.8	2.65
Limestone (Ramgangmandi)	22	6	25,370	1932	16.04×10^6	7.5	.8	2.75
Marble (Makrana)	26	7	26,316	3904	10.22×10^6	10.0	.90	2.84
Dolerite (Bangalore)	34	10	48.250	4655	18.74×10^6	12.2	.85	2.86
Phyllitic (Udaipur)	33	9	5,390	1698	3.34×10^6	2.2	.79	2.59
Syenite (Mandya)	18	2	45,048	3622	12.26×10^6	4.4	.8	2.56
Gabbro (Muddur)	25	10	38,358	3775	16.47×10^6	11.6	1.0	2.80

TABLE No. 83

(Details on next page)

(Contd......pre page)

Flakiness Index :- The flakiness of the aggregate is measured by expressing the total weight of different size fractions of the aggregate passing specified thickness gages, as a percentage of the total weight of the sample tested. The width of the thickness gages is 0.6 times the mean sieve size of the aggregate.

Angularity No. The degree of angularity is determined by measuring the proportion of voids in the 3/4 to 1/2 in. fraction of the aggregate when compacted in a prescribed way. The angularity No. is the percentage of voids less 33.

Surface Texture. Having obtained themagnified picture of the interface of between stone and resin (P. 71) the length of the profile is measured and compared with the length of an inverse line drawn as a series of chords. The difference between the two lengths is taken as a measure of the roughness or surface texture of the aggregate.

*As in case of Building Stones.

TENSILE STRENGTH OF THE CONCRETE IN Lb./Sq./in.

Aggregate	MIX 1			MIX 2			MIX 3		
	7 days	28 days	91 days	7 days	28 days	91 days	7 days	28 days	91 days
Granite (Bangalore)	890	955	965	630	710	765	450	485	525
Basalt (Bhopal)	945	1075	1080	655	735	845	450	495	565
Quartzite (Delhi)	865	870	980	610	645	710	395	435	505
Sandstone (Dholpur)	765	770	825	560	615	595	340	430	500
Limestone (Ramganj nadi)	890	965	985	650	710	765	435	495	555
Marble (Makrana)	965	990	1065	670	810	815	445	495	545
Dolerite (Bangalore)	965	1095	1105	675	755	865	470	505	585
Phyllite (Udaipur)	685	820	940	470	573	635	290	390	455
Syenite (Mandya)	915	1015	965	650	755	775	445	495	560
Gabbro (Muddur)	860	985	1020	565	710	825	430	450	520

TABLE No. 84

COMPRESSIVE STRENGTH OF THE CONCRETE IN LB/SQ./IN.

Aggregate	MIX I			MIX II			MIX. III		
	7 days	28 days	91 days	7 days	28 days	91 days	7 days	28 days	91 days
Granite (Bangalore)	9055	11355	12545	4475	6835	8135	2395	3935	4765
Basalt (Bhopal)	8785	11065	11885	4610	6715	7965	2530	3715	4530
Quartzite (Delhi)	8195	10610	11750	4210	6350	7495	2255	3440	4255
Sandstone (Dholpur)	8270	9635	10140	4575	6770	7585	2370	3725	4530
Limestone (Ramganjnadi)	8830	10275	11555	4415	6550	7565	2345	3635	4470
Marble (Makrana)	8255	10525	11570	4365	6615	7610	2285	3455	4185
Dolerite (Bangalore)	8870	11260	11995	4740	6830	8065	2630	3815	4675
Phyllite (Udaipur)	7895	9885	10470	3885	6025	6990	1985	3135	4125
Syenite (Mandya)	8390	10735	11380	4135	6230	7395	2260	3420	4260
Gabbro (Muddur)	8795	11570	12355	3965	6265	7560	2295	3375	4295

TABLE No.85.

TENSILE AND COMPRESSIVE STRENGTH OF THE MORTAR IN THE CONCRETE AFTER 91 DAYS.

Property	Mix. I	Mix II.	Mix. III
Tensile Strength	1245	810	640
Compressive Strength	11205	6035	3495

TABLE No.86

VARIATIONS IN THE TENSILE AND COMPRESSIVE STRENGTH OF CONCRETE MADE WITH DIFFERENT AGGREGATES

(Calculated from Table No. 84 and 85)

Property	MIX I.			MIX II.			MIX. III		
	7 days	28 days	91 days	7 days	28 days	91 days	7 days	28 days	91 days
Tensile Strength									
Highest	965	1095	1105	675	810	865	470	505	585
Lowest	765	820	825	565	575	595	290	390	455
Highest minus lowest	200	275	280	110	235	270	180	115	130
Average	875	954	993	614	702	760	415	468	532
Range %	22.857	28.826	28.197	17.915	33.476	35.526	43.373	24,573	24.436
Compressive Strength									
Highest	9055	11570	12545	4740	6835	8135	2630	3935	4765
Lowest	7895	9635	10140	3885	6025	6990	1985	3135	4125
Highest minus lowest	1160	1935	2405	855	810	1145	645	800	640
Average	8534	10692	11565	4238	6520	7637	2335	3565	4409
Range %	13.593	18.098	20.796	20.175	12.423	14.993	27.623	22.440	14.516

TABLE No. 87.

$$\text{Range \%} = \frac{\text{Highest - Lowest}}{\text{average}} \times 100.$$

DISCUSSIONS OF RESULTS

Strength of Concrete

It has already been pointed out and discussed in the preceeding chapter that the petrographic and mineralogic factors have a profound effect on the strength of the hardened concrete. Table No. 87 shows the variation in the strengths of concrete of the same mixed proportions. From this it will be observed that the concrete with the same mixed proportions may have different tensile and compressive strengths, depending upon the type of aggregate used in the mix.

For the same proportions (Mix. I, II & III) and at the same age the maximum range in the tensile and compressive strength has been 43 and 27 percent respectively (Table No.87) Therefore, the effects of different aggregates on compressive strength were not as great as on the tensile strength (Table No.87). Nevertheless, it has been possible to obtain an increase of 2405 p.s.i. and 280 p.s.i. respectively in the compressive and tensile strengths after 91 days. It has been obtained by using a selected aggregate in Mix I and the difference noted is appreciable.

Aggregate Strength in Concrete

On comparing the results given in Tables No. 83, 84 and 85 no general relationship could be established between the crushing strength and the tensile strength of the aggregate on one hand and the compressive strength and the tensile strength of concrete on the other. However, the aggregates made from rocks possessing low tensile and compressive strength. This indicate that possibly the effect of strength of aggregates on concrete strength is more pronounced in case of weak rock. In other words, according to the Engineering Classification of Building Stones (Fig.26) given on page 124, it can be stated that lesser the toughness number greater the influence of stone on concrete strength.

Further, from the results of Table No. 86 and 87 it is observed that the tensile strength of the mortar is generally higher than the tensile strength of the concrete. This indicates that the upper limit of the tensile strength of concrete is set by the strength of the mortar.

However, in case of compressive strength, the position is just the opposite and the compressive strength of the mortar is usually low (Table No.86) than the compressive strength of concrete. This indicates that the mechanical interlocking of the coarse aggregates, and the surface adhesion as explained on page 169 contributes to the ultimate strength of concrete when subjected to compressive loads.

Dynamic Modulus of Elasticity of Aggregate and the Strength of Concrete.

The correlation coefficient for dynamic modulus of elasticity of the aggregate (Table No.83) and the tensile strength of concrete (Table No.84) show a mutual relationship. On the other hand no coefficients could be correlated in case of compressive strength of concrete. The indications are, therefore, that the modulus of elasticity has an effect on the strength of concrete. Modulus of elasticity as determined in case of a few more rocks, by sonic and ultrasonic methods are given in Tables No.74 and 75.

Shape of Aggregate.

As stated by Kaplan[129] sometimes there is a relationship between the flakiness index and the angularity no. of aggregate and the concrete strength. According to him these two properties of aggregates are measures of shape.

Correlation coefficients for flakiness and concrete strengths were calculated and it was found that in the case of tensile strength the coefficients were significant for Mix I at 91days and Mix II at 28 and 91 days. Coefficients for compressive strengths have not been significant.

As can be seen from Table No. 83 and Table No. 84 there is a correlation between the coefficient of angularity and tensile strength for Mix. II at 91 days, while for compressive strength correlation was found for Mix I at 28 days and Mix III at 7 days. This suggests that the shape of the aggregate has an effect on the tensile and the compressive strength of concrete.

Absorption Percent of Aggregates and the strength of concrete

In all the experiments performed there does not appear to be any relationship between the water absorption capacity of the aggregates (Table No.83) and the tensile or compressive strength of the concrete mixes at either 7, 28 or 91 days. From Table No. 83 it can be seen that the variation in the water absorption capacities of aggregates used in these investigations are ~~only~~ between .8 ~~to~~ 1.0 only. This does not cause effective change in the W/C ratio and consequently in the strength of the concrete. However, it is felt that the stones like Upper Gondwana Sandstones which are highly porous, when used ~~at~~ in dry condition, may have great effect on the effective W/C ratio and finally on the strength of concrete.

SURFACE TEXTURE OF ROCK AGGREGATE & THE STRENGTH OF CONCRETE

On comparing the surface texture of aggregates (Table 83) and the tensile and compressive strength of Mix 1 concrete at 28 days and 91 days a significant correlation was found. We find there is a general correlation which exists between concrete strength and the surface texture of rock aggregates, except in case of Dolerite from Bangalore where concrete strength made with it were low. Obviously these results indicate that the surface texture of the aggregate has an effect on both the tensile and compressive strength of concrete.

CONCLUSIONS

(1) The strength of concrete of the same mix proportions is effected by the differences in coarse aggregates. It has been observed that depending on the aggregate, differences of 43 and 27 percent in tensile and compressive strength of concrete were obtained.

(2) Shape, surface texture and modulus of elasticity

of aggregate effect the tensile and compressive strength of concrete. The effect becomes more pronounced when the concrete strength is greater. The elasticity of the aggregate has been in general the most important single factor affecting tensile strength. Surface texture is the most important factor affecting compressive strength.

(3) The upper limit to the tensile strength of the concrete was set by the strength of the mortar.

(4) The presence of coarse aggregates with higher angularity no. and rough texture contributes to the ultimate compressive strength of the concrete.

(5) In these investigations, differences in the water absorptive capacities of the aggregates used were too small to have a significant effect on the strength of concrete. It may be that more porous aggregates like Upper Gondwana Sandstones, when used dry will affect the concrete strength.

CHAPTER XIII.

SUMMARY

It is surprising to note that the subject of 'Indian Building Stones, though important from many points of view, has received little attention so far. Much information is available on the building stones of other countries but the literature is meagre about Indian resources. The lack of information about Indian Building Stones and natural aggregates results too often in the haphazard selection and use of stone either as a masonry material or as an aggregate for concrete. The influence of the mineralogic and petrographic properties of rocks for quality control of concrete is extremly important from the point of view of engineering structures.

Chapter II stresses the need of mechanization of stone quarries in India. To-day most of the stone quarrying is done manually. Three tons of stone has to be quarried in order to produce one ton of principal finished product. Dressing is also done manually at the quarry using ordinary chisels and hammers. Polishing factories mostly comprise a row of labourers, polishing stone by using ordinary river sand as an abrasive. Quarry masters are not familiar with the new methods and their effacacy. Use of up-to-date saw frames, planning machines, diamond saws, carborundum saws, polishers, polishing rings and various other modern carbide tools which are used in other countries may not find application under Indian conditions. Obviously the type of modernisation and mechanization is a great problem. From this point of view a 'FLAG-SAW' which is especially suitable for the

Indian quarries producing limestone slabs and flooring or roofing tiles has been designed. It consists of an electrically operated 5 B.H.P. motor and a steel centred carborundum or silican carbide disc for cutting. The disc is screwed to a long spindle which is directly coupled through a shaft, so that it cuts the stone surface without any impediments. The whole assembly is mounted on the pedestals with rising and falling motion. Water is directed by a feed pump at a pressure of 60 lbs. per sq. in. Cutting discs are manufactured by using cheap abrasives such as garnet or corundum of the grit varying between 20 to 100 and applying phenol formaldehyde resins as binders. The whole operation of cutting a flag can be conducted by two men with an idle time of 2 to 5 minutes between two operations.

Further, out of the new methods of quarrying and sawing used in other countries, a few which can find potential utility in India have been proposed. Wire sawing plants can be used for cutting virgin deposits directly out of the quarry face. It can cut marble and limestone upto 6"/hour and 10"/hour respectively. The general layout is very simple and consists of 'Sawing Heads', Direction Pulleys', Direction Posts, Tension carriage, wire rope and turn-blocks. Out of pneumatic or electric cutters and saws for open quarries the following are suggested:

1) Vertical cutter with five drills and turning in alternate direction and working semi-automatically.
2) A cutter working horizontally for cutting slots of similar depth.

3) For hard stones, a battery of 9 steel tubes tipped with abrasive.
4) A machine carrying a drill between two circular saws, with tungsten carbide teeth. 250 mm. x 80 mm. deep, H-shaped cuts are given.
5) A machine carrying three rotating cones armed with tungsten carbide teeth forming T.
6) An electric cutter.
7) Cutters with chain
8) Cutters with double action.
9) The wire sawing machines.

With the productivity of these new methods, it is hoped that the production will increase effectively, and the price of 'Stone' will come down to competitive rates.

It has been realized that the information regarding the existing building stone quarries, their location and the type of stone they quarry is not available. The information as collected by field survey of many quarrying centres of the country and also through questionnaires issued to quarry owners and the state government departments has been tabulated in Chapter III.

The Assam being affected by earthquakes building stone quarries are not many in the state. The Andhra Pradesh is richly endowed with limestones and granites. Number of small scale quarries are distributed throughout the state. 'Cuddapah Slabs' 'Shahbad Slabs', Kurnool Slates, and 'Blue Granites', are the famous varieties available here. Bengal being mostly alluvial, the availability of building stones is scarce. However, quartzites, Gondwana sandstones, geneissic rocks are quarried at a few places. In Bihar brick industry is fully developed and this has retarded the growth of building stone quarries in this state. In the state of Gujerat, quarries have been opened in different geological formations. Basalts, sandstones, marbles, phyllites, quartzites, slates, granites, and gneisses are quarried at various places. 'Porbander Stone' is the famous variety used in this state. Granites, charnockites, limestones and sandstones are the main source of the building stone in the state of Madras. The Madhya Pradesh is occupied by Vindhyan sandstones and limestones in the north, granites and gneisses in the east and south-east and by Deccan traps in the west, south-west and south. In the Maharashtra laterite and basalts are the chief building stones, and are exploited at a number of places. 'Kurla Trap' is well known here. The Mysore State is famous for the export of polished granites and other igneous and metamorphic rocks as building stones. Variety of rocks are quarried at number of places. In the state of Orissa, granites, sandstone, and laterite are the chief varieties. Slates and the famous ornamental marble, popularly known as 'Pepsu Marble' are quarried in the state of Punjab and Himachal Pradesh. The Rajasthan is endowed with a variety of excellent building stones. It is the largest building stone producing slate in the Indian Union. Sandstones, marble, quartzites, Phyllites, and limestones of innumerable varieties are quarried at number of places. Famous red sandstone of Delhi, 'Kotah Stone' 'Fidusar', 'Black Bhaislana', 'Berla', 'Darshan Cheza', 'Harfi Haboor', 'Makrana Marble' and Jaisalmer Marble are the popular varieties. In the state of Uttar Pradesh, Mirzapur and

Chunar sandstone quarries are perhaps the oldest well organized quarries. Chapter IV deals with the experimental techniques followed for this work. The problem of ascertaining the field performance of stone as a constructional material ix very complicated and difficult, because of its varying mineralogical composition and textures have to considered against different climatic conditions. Testing of building stones have taken divergent courses, though certain test procedures are now fairly standarized. The true and apparant specific gravity, porosity, water absorption and saturation coefficients are determined according to Indian standards. Petrographic examination is a specialized branch of study and number of petrographic methods and calculations for the measurement of rock properties are available. Use is made of 'Lake Side' 70, as an impregnating material in case of friable rocks. Salt crystallization inside the pores of a stone is supposed to be the cause of disintegration of stones. A method of test for durability where 14% of Na_2SO_4 $10 H_2O$ with a density of 1.055 gm/cc. is prepared and the stone samples are suspended in it for 4 hrs. at $27^o \pm 2^oC$. Then the samples are dried at 105°C overnight. This completes one cycle and such 30 cycles are to be completed for the durability test. The change in weight is recorded as $\frac{W_1 - W_2}{W_1} \times 100$, where W1 and W2 are the weight of the specimen before and after each cycle. Compressive strength is determined according to Indian Standard and the formula used is $C = \frac{P}{A}$ where C is the compressive strength in lbs/sq.in. and P is the maximum load sustained by the specimen. Determinations of modulus of rupture is per I.S.S.

No. 1121 and the formula used is $R = \frac{3WL}{2\ bd^2}$ where R is the modulus of rupture in lb/sq.in, W is the central breaking load in pound, L is the length of span in inches, b and d are the average width and depth of the specimen at mid section. Similarly 'Shear strength is calculated as $S = \frac{Wt-W_1}{,DT}$, where W_t is the total, maximum load in pounds, Wl is the initial load in pounds required to bring the plunger in conctact with the surface, D is diameter in inches of the plunger and T is thickness of the specimen.

Determination of the 'Dynamic Modulus of Elasticity' was done by 'Sonic' and 'Ultrasonic' methods. With Sonic tester resonant frequencies in the transverse mode of vibration of the specimen was determined. The frequency response curve at the resonant frequency was obtained. The dynamic modulus of elasticity was calculated using equation $Ed = CW\ (n_t)^2$ when

$C = \frac{.00145\ L3T}{bt^3}$ T is the Goen's correction factor and L,b,t are the length breadth and thickness of the specimen. Ultrasonic phase velocities through the specimen are also determined by measuring the time taken by a wave to travel from one end to the other, electronically. The relation of the 'Ultrasonic' pulse in a medium will depend on the modulus of elasticity and density of the stone and the relation is given by

$$VL\_\sqrt{\frac{E}{\rho}\ \frac{1-\sigma}{(1+\sigma)\ (1-2\sigma)}}$$

where VL is the ultrasonic pulse velocity, E is the modulus of elasticity, ρ is the density and σ is the poisson's ratio. In a finite medium the formula reduces to $VL = \sqrt{\frac{E}{\rho}}$.

Chapter V pertains to physical properties like apparant specific gravity, true specific gravity, Wt/Cu.ft., microporosity, macroporosity, total porosity, pore-structures and saturation coefficient together with the Chemical Composition of Indian Building Stones. From the study of the apparent specific gravity true specific gravity and Wt/cu.ft., it appears that the apparant specific gravity is more directly connected to the Wt/Cu.ft. than the true specific gravity. This is due to the presence of pore spaces within the sample which play an important role for evaluating a stone. Hence, the apparant specific gravity is more significant than true specific gravity in case of natural building stones.

Absorption capacity of rocks depends upon the shape and size of grains, and the texture. Simple, immersion in water does not lead to complete saturation as the water fails to reach those pores which are completely cut off and there is no access of water to that part of stone so that the replacement of the entrapped air is incomplete. Studies on the properties like saturation co-efficient and microporosity, macroporosity and porosity ~~stones~~, indicate no relationship in case of stones. The saturation ~~of~~ co-efficient measured under constant conditions is a characteristic property of the stone and besides other factors, depends upon the configuration of the pores. However, absorption affords a crude measure of pore-structure and it has been realized that an attempt to evaluate the pore-structure quantitatively shall be a definite advance towards durability studies in case of natural building stones.

The phenomenon of efflorescence in case of building stones and its relationship with the chemical composition of stones under the variable conditions of weather such as that of tropical countries, is of special significance. From the studies on the chemical analysis of building stones given in Chapter V it has been observed that almost all rocks ranging from sand-stones to granites and slates etc. have magnesium and calcium salts in their composition. These salts on weathering, get accumulated at the surface of stone as efflorescence causing disruption.

In Chapter II, Engineering Properties like compressive strength, modulus of rupture and shearing strength of Indian Building Stones have been discussed. During the test it was observed that the cubes of the same rock, having the same size shape and character of bearing surfaces failed under different loads. The cause of these variations in strength lies in

a) Faulty method of quarrying
b) Distribution of micro-cracks and incipient plane of cleavages in stone and their distribution in relation to loads.
c) The degree of dryness in a stone.
d) Seasoning time.
e) The degree of Weathering.

With a view to ascertaining the relationship, the compressive strength and the modulus of rupture, have been studied. There is a significant relationship between these two engineering properties, though the degree of variation is different in case of different rock types. Consequently no general relationship could be observed. Similarly, the relationship between compressive strength and the shearing strength has been studied and discussed both for the values of the shears parallel as well as pendicular to the rift planes. Each type of rock has a curve of its own for this relationship. On the basis of the above relationships, it can be generalized that the compressive strength of a stone gives a fair indication of the other two engineering properties.

In order to simplify the use of 'Building Stones' in the engineering field and also for the purpose of trade in order to decide the cutting rates a new scheme of classification of 'Building Stones' under Indian conditions has been proposed. Regarding the basis of classification, it has been established that on one hand wt/Cu.ft. gives a fair indication of the reqd. physical properties in case of buildings stones and on the other hand compressive strength bears close relationship to the other engineering properties. Hence, a physico-engineering relationship has been obtained in the form of a general curve. The equation derived for the above relationship is -

$$C = \frac{5 \times 10^5}{195 - W}$$ whire C is the compressive strength in p.s.i. and W is the Wt/Cu.ft.

On the basis of the above law of variation, as derived from the present studies, the rocks have been classified into 15 classes. In this classification each number indicates a particular class of rocks possessing similar physical as well as engineering properties of stones. Further the classification and the general equation can be utilized to obtain theoretically the approximate compressive strength of a stone or wt/cu.ft., if one is known. From compressive strength other engineering properties can always be ascertained by refering to the respective curves for those relationships. Since, these respective curves are different in case of each type of rock, the classification should be treated in a restricted way as suggested and should not be extended to all other physical and engineering properties directly. Such an attempt would mean de-classification.

Chapter VII reports the Dynamic Modulus of Elasticity in case of building stones of India, as determined by 'Sonic' and 'Ultrasonic' methods. The results obtained by these two methods show close concordance except in a few cases where the inherent defects have been pointed out. These defects cause either reduction or increase in the propagation of the pulse velocities. Parting surfaces in case of flag stones, bedding planes, cleavages and their disposition seriously effect the values. Similarly the relationship between dynamic modulus of elasticity and density has been established. Here also, the deviation of the points from the general curve are indicative of some unknown, unexpected inherent differences in the composition, texture or structure of the rocks. Pulse velocities are higher in case of fine grained compact rocks, whereas coarse grained heterogenous stones mass always retards the pulse velocities. Crystal boundaries between two minerals also effect the propagation of the waves. Compressive strength as related to Ultrasonic elasticity has been discussed. This indicates a close relationship between the two properties.

On the basis of the ultrasonic pulse velocities, a method has been proposed for the determination of the 'Grain' (Cross fracture) in case of slates. Ultrasonic waves travel faster in the direction of 'Grain'. The behaviour being same in case of heat waves also, a test is devised where a coating of a mixture of the double iodide of copper and silver in the ratio of 85% and 15% respectively is laid over the slate surface. Slate is then, heated from the opposite side by a pointed flame in the centre. The direction, along which colour changes are more rapid is the direction of 'Grain' or cross fracture.

In Chapter IX, the influence of the physical, engineering and petrographic properties on the durability of building stone, WITH REF. T. durability curves have been studied. It has been noted that certain properties of stones though important from durability and strength point of view in a stone remains undetected during the standard test for durability. Obviously in order to have a better understanding of those factors of durability under different conditions and also to study the phenomena of strength development in case of stones, an insight into the various aspects of their petrographic characteristics have been studied. It has been observed that the physical and engineering properties of stones are ultimately the functions of their mineralogic and petrographic properties. On this basis, the durability of a rock can be expressed petrographically as a dependent variable in a multiple regression equation such as, $W = f(X_1, X_2, X_3 - X_4)$ where W stands for durability expressed as a function 'f' of the independent petrographic variables ($X_1, X_2 \ldots\ldots X_4$) determined quantitatively, such as grain size, grain packing and uniformity of surface texture etc. as the case may be.

Theoretically, the strength of a stone, as dependent upon the coherence of its particles might be taken to imply identical resistance to every disintegration force. On comparison of the results of durability studies and the 'Numerical Classification of Rocks', it has been observed that there is no definite parallelism between the structural strength and the durability of a rock. Though the compressive strength, modulus of rupture, shearing strength or modulus of elasticity may reach thousands of pounds per square inch, yet it gives no idea of durability or actual strength of a stone which enables it to stand against the vararious climates of India.

The term, "Durability" so far has been confined for the chemical reactions resulting in the disintegration of stone due to salt deposition within the pores and micro-pores. The term is defined here as "A Characteristic property of a stone with regard to its wear and tear in obedience to various physico-chemical, atmsopheric and engineering forces, prevalent under a particular field condition".

The actual foundations on which the method of trials and tests for durability and strength in stones should rest, have been broadly classified into four classes -

A. Interlockment or granular arrangement
B. Coherence
C. Tension or Strain
D. Rigidity.

Three types of interlockment or granular arrangement have been distinguished - (i) irregular aggregation, (ii) parallel sorting, (iii) devetailing or interpenetration. Besides the strength developed by the interlockment of mineral grains of stones, two modes of coherence - (i) cementation and (ii) molecular cohesion, prevail in building stones. Cementation is mainly present in stones of sedimentary nature. From the petrographic studies of sandstones and its comparison with engineering properties, it appears that silica cement is the most powerful out of all natural cements. This, in the form of compact cryptocrystalline mass binds together a large part of the otherwise loosely pulverulent sandstones of Vindhyan system, into solid orthoquartzites. In crystalline stones strength is mainly due to another physical force, the molecular cohesion which exists between surfaces of mineral pressed into intimate contact. In consequences of the tremendous force involved in molecular and capillary adhesion surfaces cohere very strongly as seen in case of marbles and crystalline limestones. They exhibit the same aggregation of tangent planes and correspondingly to high compressive strengths.

Regarding tension or strain, the petrographic examination of igneous and metamorphic rocks, it appears that there is always a certain amount of balance of stress and strain among the mineral components of a stone. Any disturbance of this by increase, loss expansion or contraction, tend to injure the tenacity, coherence and permanence of the aggregates of minerals in a building stone. These tension or strains may be produced due to (a) crystallization forces of minerals, (b) subterranean forces, (c) changes in tem-

temperature which results in 'Sugaring' of marble.

Rigidity or in other words, the lack of plastic deformation capacity is of great importance from the durability and strength point of view when the stones are subjected to great pressures in large engineering projects. Cleavages and the sliding surfaces are the two main factors causing such plastic deformations in case of building stones.

Seasoning of stones, resulting in the development of strength is attributed to the hardening of the deposited films of lime, magnesia, iron carbonates and oxides. Lime sulphate, silicate of soda, potash, lime magnesia and other bases and even dissolved colloid silic acid - crystalizing as quartz or in the amorphous form of chalcedony or hyalite, also generally serve as factors in the phenomena of cementation during seasoning of stones.

Chapter X describes the defects and difficulties of the stone masonry in India. As illustrated the stone is used in external wall facings in three main forms in India (i) as rubble in a solid wall (ii) as rock faced courses in the outer skin of a cavity wall, (iii) as ashler in the outer skin of a cavity wall. In absence of standard specification of the methods of construction, number of common defects such as placing of the stone in a face bedded position, construction of thresholds and steps in the early stages of construction, improper choice of colour combinations, poor mortar for jointings and pointings, mortar dropping over finished surface, cavities in joints of coarse ashler, insertion of logs at random and loose projecting of horns for doors and windows have been noted.

Studies on the proper utilization of stones, have shown experimentally that the chips made from 'Black Traps' for terazzo tiles and mosaic flooring take good polish and are quite comparable to the marble chips, if not superior. Similarly stone beams of all kinds are plentiful in India and very useful trusses can be made from them. A design of stone trusses has been suggested where stone beams upto a span of 20 ft. can be used. Rafters consist of beams 12 to 5 inches thick, placed 3 ft. apart (Fig. 38 & 39). Slate roofs are quite common in India but every roof is made in a different style and haphazard way. This reduces the life of a slate roof besides the heavy maintenance expenditure and trouble. With this in view specifications for the correct method of laying slate roofs under Indian conditions have been proposed. The position of 'Pitches, 'Laps and Gauge', Nailing, 'Placing', Roofing Felt', 'Ridges', 'Dips and Valleys' and 'Flashing' methods have been mentioned and illustrated.

As discussed in Chapter XI, the influence of the petrographic and the mineralogic properties of rock aggregates for quality control of concrete is an important factor. Concrete briquettes were made with various rock forming minerals in 1:4 ratio by volume and the properties of such concretes were studied. Quartz gave a concrete having a tensile strength of nearly 340 p.s.i. on autoclaving at 150°C for 24 hours. Other forms of silica which include flint, chert and chalcedony give much higher strengths than quartz. This is attributable to more free bonds being available on the surface of cryptocrystalline varieties.

Strength of concrete in which felspars alone have been used is higher than that of quartz, but it is interesting to note that on stream curing the strength of concrete made from felspars, get reduced. Higher the percentage of alkalies in a felspar, the lesser the strength obtained by autoclaving. Further, it has been noted that the effect of 'K' ions is greater than 'Na' ions. Ferromagnesium minerals such as amphiboles and pyroxenes are tough minerals and tend to confer the same toughness on rock aggregates. Mica due to its soft and flaky nature is supposed to be a harmful impurity when present in large quantities. The most satisfactory mineralogical composition of a rock is, where, quartz forms 25%, felspar 40%, Augite and Hornblende 20% and Mica less than 10% of the whole mass. Grain size should be between 2.3 mm. and 0.4 mm.

A distinction has been drawn between 'SOFT' and 'WEAK' particles in concrete aggregates. Softness, as defined by Moh's, designates yield to abrasion, whereas the weak particles are the product of decomposition either of soft or hard minerals. Both soft and weak particles should be at minimum, though soft particles sometimes offer a good bond and molecular cohesion.

In coarse granites where mineral quartz lies in contact with the relatively smooth surfaces of the early formed crystals of felspar and amphiboles low strength in an aggregate is expected. The granophyric texture indicates a strong key. Ophitic texture is an advantage for making high quality rock aggregate. In sedimentary rocks angular, subangular and sutured grains add to the st--strength. In metamorphic rocks the nature and quality of the aggregate is dependent on the nature of the original composition of the rocks and the degree of metamorphism. According to Rau rocks having a high modulus of elasticity develope correspondingly higher module in concrete. Modulus of elasticity of a few Indian rocks has been determined.

Rocks have been classified into two groups depending upon their chemical stability in concrete :

A. Reactivity independent of cement.

B. Reactivity between a cement component and mineral constituent of an aggregate.

Oxidation, 'Hydration, 'Carbonation' and 'Soluble Minerals and clay fractions fall within the first category, whereas 'Base Exchange' and alkali-aggregate reaction in concrete fall in the second type.

It has been noted that certain clay minerals are responsible for causing excessive shrinkage in rocks of sedimentary nature. This causes ultimate failure in concrete. In case of two stones tested, gave shrinkage percentage from .021 to 0.79.

Fire resistance properties of aggregates have been briefly dealt with. Average co-efficient of thermal expansion of rocks on the basis of silica percentage has been calculated and discussed.

Chapter XII deals with the role of coarse aggregates in the development of strength in concrete, the importance of which can be judged from the fact that it occupies a volume of approximately 43% of the concrete mass. On quantitative estimation of the influence of the mineralogic and petrographic factors on concrete strength, it has been observed that differences of 43 and 27 percent in tensile and compressive strength of concrete respectively can be obtained.

Shape, surface texture and modulus of elasticity effect the tensile and compressive strength of concrete. Tensile strength is affected mostly by the change in modulus of elasticity, whereas compressive strength is affected by the surface texture. The upper limit of the tensile strength of the concrete is set by the mortar strength. The presence of coarse aggregates with higher angularity number and rough texture contributes proportionately to the ultimate compressive strength of the concrete. Water absorptive capacities of the rocks in these experiments ranged only between .8 to 1.0. This does not cause any éffective variation in W/C ratio and consequently the concrete is also not effected. However, Upper Gondwana Sandstones when used in dry condition will change the W/C ratio which will definitely reflect back on the strength of tho concrete ultimately.

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