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RHYME AND REASON

" . . . It takes rough seas to make good sailors and great captains."

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THE DEMAND PATTERNS OF INDIA OF TOMORROW

BY

DR. K. L. RAO.*

DR. SEN AND FRIENDS:

I deeply appreciate the honour you have done me by inviting me to deliver the Dr. Visvesvaraya Memorial Lecture, and I thank you for it. Dr. Visvesvaraya was a stalwart among men, as he was a giant among engineers. He will ever be remembered as one of the greatest Indians, and this city of Hyderabad itself owes a debt to him. It was his plan of 1909 for controlling the Musi that has freed Hyderabad from the menace of floods, that has provided the expanding population of the city with an unfailing source of water supply. I feel that Hyderabad should erect a statue to Dr. Visvesvaraya.

Dr. Visvesvaraya was a bold dreamer. But the engineer in him always enabled him to keep his feet firmly on the ground. Therefore, his flights of imagination were practical dreams. He himself shaped many of them into magnificient form and it is left to us to bring the others to reality.

Mysore was his experimental laboratory. His theories, his views and his ambitions for the advancement of the people—he tried them out, on a pilot plant scale as it were, in the State. There was no aspect of people's welfare or economic endeavour or nation-building that escaped exhaustive study at his hands. And he touched nothing which he did not improve upon immeasurably. Whether it was the system of irrigation, or development of banking and commerce, or education of women or industrialisation of the country. Dr. Visvesvaraya laid a plan, a programme, a blueprint for execution. And every one of them was based on down-to-earth facts and figures. He was an engineer to the core: he insisted on data, *all* necessary data, and *correct* data, before he considered the subject. He insisted on systematic collection of statistics. Our planning today could have been easier, more far-reaching, if only the government of his time had followed his advice. And that holds good for industrialisation too-rapid, nation-wide, all-round industrialisation. He was the champion, the apostle of industrialisation that at a time when the foreign rulers were silently averse to it, when many of our own people, without seeing the writing on the wall, without an eye for the future, were crying against the machine and modern industry; when they were still wazing eloquent on the beauties of primitive methods in villages.

There were two traits in his character which must be emulated by all of us. His high sense of integrity. He kept separate pens, one for *office work, one for private correspondence.* He used to smilingly explain that if he used the same pen for both, the ink provided by the Government might come to be utilised for his private use.

Another fine trait was how he raised the self respect of his countrymen. He wanted every Indian to hold his head high and feel equal to his counterpart in any country. He deprecated any inferiority, even in a subordinate. Once when he was touring a district as Dewan, the Deputy Commissioner introduced his Assistant Commissioner. The Assistant Commissioner bowed humbly and said that he had the privilege of serving *under* the Dewan Sahib earlier in the Secretariat. Dr. Visvesvaraya at once corrected him: "I know you were working *with* me, not *under* me."

Dr. Visvesvaraya's PLANNED ECONOMY FOR INDIA is a precious testament and will of a great engineer for his country. The effort the vision and the faith of the men are enshrined

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in it. The greatest homage we can pay to a dedicated life like his is to carry out his message, to extend and enlarge his message of economic development of India. He has laid out in it the lines of development, the methods and the philosophy of development for the nation.

2. The Present

India, with 450 million people inhabiting 806 million acres of territory, is in the category of developing countries. Only three hundred years back, she was one of the most prosperous nations of the world. Since then, due to loss of her independence, and her failure to participate in the scientific and industrial revolution, she slipped down to poverty, and she is now unable to support her own people. Of every basic need-food, power, clothing and shelter-she is far below the mark. Against her minimum food requirement of 100 million tons in 1966, she is now hardly able to produce 80 million tons, compared to the total production of 1,000 million tons in the world. In power, the installed capacity is only 7 million kilowatts, or 1.3 per cent of the world figure. For the barest coverage of the body, she has to import cotton from outside costing 70 crores of rupees of foreign exchange every year. From this stage, she has to march ahead rapidly. This march started in 1951, toward the set goal of a more prosperous way of life-a march unprecedented in world history of a vast nation in its search or well-being through peaceful developmental works.

It is important to study the reasons for the deterioration of India's economy in the recent past in greater detail, specially because in the field of metaphysics, religion and mathematics, her attainments were once impressive. As I said earlier, the main reason in her non-participation in the scientific age which commenced in reality from the days of Galileo (1564-1642 A.D.—the famous years in which Shakespeare and Isaac Newton were respectively born). Galileo had immense difficulties in disproving the dogmatic statements made by Aristotle in 384-322 B.C. From about this time began a stream of discoveries and inventions, such as the physical laws, the steam and diesel engines, electric power, etc. The later discoveries of rockets, turbojets, computers, automobiles, etc. indicate the staggering pace of the new scientific age. Men of each generation have passed on their observations to the next, and science has grown through the ages by collective effort. Science and technology always grow on the shoulders of earlier giants. We in India were completely left out of this gathering momentum of hectic progress.

Scientific development in the last three centuries can be divided into two broad classes—pure science and applied science. Pure science aims at original approach, interpretation and formulation of natural laws of behaviour of matter. It has already a bearing on the daily life while applied science is a deliberate attempt to influence the mode of life for the better. Engineering technology and medical science come under this category. This dominating influence of technology in modern life is so great that it can be said that we are living in a Technocracy instead of Democracy. Whatever we use in our life, right from the early morning till we go to bed, everything is an application of science. Man has applied science in getting benefits from nature according to the circumstances. The sciences are the languages of nature and the engineers have used them in extracting benefits from nature.

Engineering is a service to mankind. It is a field of activity which eschews violence, and satisfies both man's desire for order and his craving for change. It endows society with an approach of reason to its problems, and ensures stability of the community. It offers by far the surest and safest way to improve the backward lot of the majority of mankind.

3. Tomorrow

To this wonderful panorama of the rise of technology, we are recent entrants, having woken up from a forced slumber. We should also remember that independence and planned development has bread in India, a revolution of expectation—the slow elimination of the depressing attitude of fatalism. The Indian has rightly begun to feel that there is no reason why he should not have sufficient food, adequate clothing, a roof over his head, employment for himself, education for his children and health for all. We have to take steps to meet not only the present demands but also the mounting demands of tomorrow.

I have taken "tomorrow" to cover up to 2,000 A.D., that is, only 35 years ahead of us. This round figure is not far off, nor is it short for developing a progressive picture of the shape of things to come. For serving as a base, I propose to take the economic conditions prevailing some 40 years ago in such of the countries as were close to our present conditions. The growth of economy between 1920 and 1960 for USA and USSR and JAPAN are given in Table-I. The nearest parallels, I think, would be the USSR at the time of the 1919 revolution, and Japan just before the First War. The world economic survey of 1931-32 published by the League of Nations states: "Russia is one of the prodigies of the time. From backwardness, it has advanced at a stride to the forefront of mechanical development." Japan, when she started modernising at about 1870, was in the same position industrially as India was at the time. The money she made from early enterprises, she went on investing in expanding industry and trade. Particularly during and after the First War, the progress was extraordinarily rapid. The income from manufactures rose from Rs. 206 crores in 1914 to Rs. 937 crores in 1925, a rise of over 355 per cent.

I am aware that the analogies cannot be perfect because politically the conditions were different in those countries, the state of technological advancement of the world was further behind than today, the methods of achievement, the nature and character of the people in each of the countries and many other tangible and intangible factors differ considerably from country to country But I hope it will be realized, we can only use instances which are nearest to ours for comparison. By this approach, the castle we plan for the 21st century will not be in the air. On the whole, my thesis is, it should be possible for India, which can learn from the experience of similar countries, and avoid the errors and pitfalls of others, to achieve more or less as much within a corresponding span as those countries have been able to do.

The first fundamental on which all development depends is the size and rate of growth of population. It is in fact to meet the needs of the entire growing population that our plans and economy have to cater. Quite a few pointers are available to us as to the population trend in the coming decades.

At present, the growth rate exceeds 2.2 per cent per annum. But we have seen in the West and in Japan that prosperity breeds ambition, just as we know that poverty breeds recklessness. As employment and income rise, the urge for restricting the size of the family also rises. We may therefore assume—since family planning is a national policy, as in Japan, where even abortion is legal—that the growth rate will soon stabilize at about two percent. The population estimates for 2,000 A.D. vary between 800 and 1,000 million, say 900 million, is, double our present population. Now, I shall try to assess the nation's requirements in the major sectors.

(i) Water

Just as power is required for energising man and fertilising industry, water is required for the growth of plant life. Irrigated lands yield far more than the non-irrigated. It is estimated that out of the total land area of the world, less than one per cent is irrigated. The cultivated area of the world is ten per cent of the land area. Table II gives the land utilisation pattern in India. Still the watered areas grow sufficient food for 25 per cent of the world's population. In India, we have at present 324 million acres under cultivation. Of this, only a total of 70 million acres are being irrigated; of this 44 per cent is under major and medium irrigation. Thus minor irrigation accounts for 56 per cent of the irrigated land. It is to be remembered that in a large country like india, proper and timely rains do not always occur all over the country and minor irrigation under tanks is the first casualty in the event of failure of local rain-fall. It is, therefore, necessary to consider only a portion of the area under minor irrigation as effective and non-failing. In India we have possibilities to extend irrigation to 100 million acres under major and medium and 75 million acres under minor irrigation due to surface and sub-surface extractions. On completion of the projects undertaken so far in the three Plans, 43 million acres will be irrigated under major and medium projects, and 47 millions under minor schemes. This indicates that we have still a long programme to go through. Fortunately, we have still a few good projects that can be exploited. In the Narmada Valley, Navgaon alone can supply water for 4 million acres.

After all the possible irrigation projects are completed, it will be possible to produce 120 million tons of foodgrains. By double cropping, improved methods of cultivation, use of fertilisers and other modern agricultural practices, the output can be increased by 50 to 100 per cent at least. This will enable us to supply a minimum of balanced diet to India's millions at the end of this century. It is interesting to note from Table-II that there would not be any increase in sown area between now and 2000 A.D. Table III shows the present yields and future requirements of agricultural products. Thus the foodgrains have to be increased from 80 million tons to 200 million tons.

Water transports

Waterways are another important item to which we have to pay increased attention. With heavy addition of population and saturation of rail transport, it will become increasingly necessary to transport, agricultural output by either waterways or roadways. In view of their cheapness, the former have abundant advantages. If at the present we cannot provide navigation due to insufficiency of funds, we should not cut them out altogether. Specially there are some important water highways which we should particularly keep in mind. Connecting the Brahmaputra with the Ganga at Farakka, and the Ganga with the Arabian Sea through the Narmada will provide an east-to-west cross country waterway of immense economic value.

Drinking Water-Supply

Drinking water for rural and urban areas is another problem which has to be solved in India. The value of Public Health Engineering in this country has yet to be realised. Industrially advanced countries like Great Britain and West Germany are grappling this problem with new techniques. Plastic pipes are being used to serve rural parts in the United Kingdom. Automatic filtration plants, capable of self-cleaning are becoming a normal feature, to reduce man-power requirement. Sewage disposal works in urban areas are another necessity requiring immediate attention. 'Oxidation' ponds recently being talked about seem to have an application in certain areas. Continuous research leading to evolution of cheap techniques is greatly needed. We must aim to provide water supply for all and sanitation facilities for all towns with a population of more than 5000, that is 6600 towns and big villages at present.

(ii) Power

An abundant supply of energy forms the most decisive factor in the economic development of the country. It is therefore most essential for any appraisal of conditions in the future, to examine the prospects of development of energy resources, in general and in the form of electricity, in particular.

Some peculiarities of energy supply in India at present require to be noted first. Whereas in countries of Europe about half of the energy consumed is now utilised in the form of electricity or gas, in India, the bulk of energy supply is being derived from non-commercial sources, i.e., cow-dung, wood and farm wastes, etc. It has been estimated that the contribution from non-commercial sources has been of the order of 60 per cent to 70 per cent of the total energy consumption in the past decade, out of which fire-wood alone probably provided about 40 per cent. The contribution of electricity has been very negligible, forming only about 4 to 7 per cent of the total energy consumption. Even as a proportion of the commercial energy supply (coal, oil and water power), its contribution has not been

more than 13 to 18 per cent. However, as the country is being rapidly industrialised, and since electricity constitutes the most flexible form of energy, the demand for electricity in India should be expected to grow at a much more rapid rate than all other types of energy. It is interesting to point out here that the average rate of growth of consumption of electricity during the last decade was 11½ per cent, while that of coal and petroleum products have been 5 per cent and 8½ per cent respectively. The high efficiency and versatility associated with energy in the form of electricity has been responsible for its replacing other forms of energy as the main source of mechanical power. In the domestic sector, which so far relies almost entirely on cow-dung and firewood, both of which require to be conserved for other purposes, the scope for replacement with electricity is even greater in the absence of adequate resources of equally convenient forms of energy like oil and natural gas. All factors considered, the potential demand for electricity in India may be considered vast.

One has also to examine very critically the resources available for energy production on a commensurately large scale. Although according to the current pattern of energy use and trends fore-seeable in the next 2 or 3 decades, the available resources of conventional commercial energy, viz., coal and water power, appear to be adequate to meet the requirements of country, it has to be examined whether the known resources of conventional fuels would be adequate to meet the long-term requirements of energy towards the end of the century. The special measure to be taken even at this stage to ensure that these long-term requirements are met and that a shortage of energy does not hold back the future growth have then to be considered.

Magnitude of future requirement

As explained earlier, the demand for electricity can be expected to grow more rapidly than for most other forms of energy. There are, however, considerable difficulties in forecasting long-term trends primarily since the growth of demand for electricity depends on many uncertain factors, e.g., the overall rate of growth of the economy, the growth of population, the extent to which electricity is required to substitute other existing sources of energy, etc. Lack of adequate resources of conventional fuels, i.e., oil, natural gas, etc. which forms an important source of energy in a modern industrial economy, also complicates assessments of future electricity requirements.

The Picture by 1980

Studies have been carried out by the Energy Survey Committee appointed by the Ministry of Irrigation and Power based on physical assessment of the demand for electricity today and its clearly fore-seeable rates of growth in the context of overall energy development during the next two decades. On this basis, it has been estimated that an installed capacity of the order of 60 million kW. may be required by 1980-81, on the basis of a steady growth of 7 per cent in the country's economy, which, according to current thinking, is essential to realise our social objectives. This would increase the per capita generation potential of electricity from about 100 expected at the end of the Third Plan to about 400, on the basis that the population of the country by the end of 1980 would probably be about 700 million.

The magnitude and distribution of the requirements for electricity in 1980 are such that practically all of these can be met by conventional power resources of water power and coal. The economically utilisable hydro-resources within the territorial limits of the country has been estimated at about 40 million kW at 60 per cent load factor. This potential can meet much higher loads at lower load factors. By 1980, about 30 million kW of hydro capacity can be installed, and used to operate at 40 per cent load factor, drawing upon roughly 50 per cent of the estimated limit of economically utilisable hydro energy resources.

On the coal front, the by-product coals from washeries, have necessarily to be consumed and additional requirements met by coal savings purely for use in thermal stations. According to the target of steel production set out for 1980 which envisage an annual production of 47 million tons of steel (corresponding to an overall growth of 7 per cent), the by-product fuels thrown out from the coal washeries to be installed in this connection, would be of the order of 60 million tons which could feed about 18 million kW of thermal power plant capacity. In addition to the 7 million kW of thermal plant capacity (out of which six can use washery coal) installed by the end of the Third Plan, and the new washery oriented stations totalling 12 million kW, it is expected that a further 6 million kW of thermal plants would have to be located at or close to the outlying collieries of Madhya Pradesh, Maharashtra and Andhra by 1980, raising the total thermal station capacity to about 25 million kW. The approximate coal consumption for the thermal stations by 1980 would be about 80 million tons at prevailing standards of efficiency. (The rest of the 5 million kW would have to be met by nuclear stations). The total raisings of coal by 1980 to meet the requirements is expected to be of the order of 300 million tons. Against these annual requirements the country's known reserves of coal now placed at about 1,30,000 million tons appears ample.

The important heavy electrical public sector manufacturing centres at Bhopal, Ramachandrapuram and Hardwar, on full development by about 1971, are planned to turn out thermal generating plants at the rate of 3 million kW per year and hydro units at the rate of 1.7 million kW. These can be augmented to slightly higher targets for 1980, thus ensuring self-sufficiency in the Primary equipment required for electricity production. It can also be safely expected that, with active participation of public and private sectors, the requirements of ancillary equipment, e.g., about 40 million kVA of transformers, switchgear, etc., can also be indigenously produced. If the above programme is effectively implemented, no great difficulties need be anticipated by 1980.

The Picture by 2000 A.D.

Trends of developments during the period up to 1980 could be extended directly through the last two decades of the century to arrive at a rough first assessment of the electricity requirements by 2,000 A.D. By 1980, the country would have reached a fair stage of industrialisation and further growth can be expected to conform more or less to the present pattern of industrially advanced nations. The general experience in these advanced countries is that growth of electricity development generally corresponds to a re-doubling period of about 8 to 10 years. On this basis, it would be seen that the total installed capacity in the country would have to rise to something of the order of 240 million kW. at the end of the century. While this may appear too ambitious from the point of view of our present standards (with an existing total plant installation of 7 million kW), on the basis of a population of about 900 to 1000 million expected by that time, the per capita generation would only be of the order of about 1000 which is far below that of almost every industrially advanced country today. This overall target of about 240 million kW by 2000 A.D. is therefore some thing for which we should prepare ourselves. We shall now examine the extent to which the country's resources would be able to sustain such a programme of development.

Probable pattern of development of 240 million kW of plant capacity by 2000 A.D.

That future electricity development would have to be based on power supply through Regional Grids, which merge ultimately to a single All-India Grid, has already been widely accepted. From the point of view of power, it has been found convenient to constitute five such regions, the Southern, the Western, the Northern, the Eastern and the North-Eastern region. The problem of increasing the installed capacity in the country to about 240 million kW by 2000 A.D. has been examined within this framework, the general trends in these regions being preserved substantially as at present.

The value of hydro stations in the earlier stages of development would be both on account of their energy potential and peaking capacity, whereas during the latest stages of development, the main importance of the hydro schemes—with

their power installations suitably expanded—would be on account of their tremendous advantages for meeting peak demands in the most economical manner. On these consideration, coal based thermal generation, utilising modern techniques, forms close second to hydro development. However, a potential for installing thermal stations on the large-scale required at the end of the century would have to be considered, taking careful account of the problem of coal mining and transport. All the collieries of the Bengal-Bihar belt as well as those of the outlying field in Orissa, Madhya Pradesh and Andhra would have to be fully developed for the purpose. These stations would command a large sphere of influence, extending through the States of West Bengal Bihar, U.P., Madhya Pradesh, Maharashtra and Andhra. Taking into account the distribution of different types of resources and their relative economics, it would appear that the capacity required by 2000 A.D. can be derived from about 100 million kW of hydro installations, working hydro plants at 25 per cent load factor, about 100 million kW of coal-based thermal installations, operating at base-load the balance of about 40 million kW coming from nuclear plants.

Some broad conclusions emerge

The programme of hydel development will utilise all the presently estimated potential, leaving small margins only in the North-Eastern region. The coal requirements for thermal stations aggregating to about 100 million kW operating at the base load out of an 80 per cent load factor is estimated at about 400 million tonnes annually. At the end of the Third Plan, the programme of mining of coal envisages a target of 100 million tonnes per year, of which only about 10 per cent or 15 per cent are for electricity production. The production of coal used for electricity production would, of course, increase with time. However, in the absence of more convenient fuels there would be a continued dependence on coal for most industrial development and probably for a good part of railway traction. Even assuming that thermal power production accounts for about one-half of the total coal production in 2000 A.D., the annua raisings of coal by the end of the century woul be of the order of 800 million tonnes. Allowin for (a) the fact that out of the known resource of coal slightly more than half may be actuall recoverable and (b) for the consumption of coa during the next 35 years, the resources of coa left for further development would be only abou 40,000 million tonnes—coal utilised at the rat of 800 million tonnes per year—would be avail able only for a short period of about 50 years In view of our limited coal reserves, we will hav to restrict the use of coal to essential purposes.

It is in this context that the importance o nuclear resources has to be appreciated. Whil there may be certain doubts about the extent t which nuclear development has to be under taken at the present time, there will be no ques tion that the bulk of the energy generated afte 2000 A.D. would have to be inevitably met fron nuclear power resources. Most current nuclea technology is based upon the utilisation o uranium either in its natural form or as enriched The proved resources of uranium in the countr of about 2,000 tonnes according to the lates estimates are barely sufficient for the operation o one Million kW of nuclear plant capacity for it expected life. However, the country's know resources of thorium of 500,000 tonnes ar reportedly the largest in the world and can b expected to sustain a massive programme o nuclear power development, once the techno logical programme involved are satisfactoril over-come. Thorium in its natural form coul be used to fuel nuclear stations, but it has to b first converted to fissile material. Specia methods would have to be evolved for this con version and suitable nuclear reactors designe before thorium can be utilised to generate nuclea energy in an economical manner. Efforts to wards this end would have to be carried out ir time, since the future programme of electricity production in this sub-continent is so essentiall tied up to these developments. It should even be considered whether the total investment being made on nuclear developments in India should not entirely be concentrated on this subject especially during the coming decades, when conventional resources can meet all our requirements.

An inescapable conclusion is that, whereas the picture by 1980 indicates hardly any necessity for nuclear power generation on a very extensive scale or reveals any serious inhibiting features, the picture by 2000 A.D. brings us perilously close to the full utilisation of the country's resources of water power and of virtual elimination of our coal resources as proved and estimated at present. This, of course, is due to the well-known fact, that compared to the industrially advanced countries of Europe and America, the resoures of fossil fuels in India are meagre. Attention has naturally to be immediately focussed on the problem of conversion of these limited fuels to the maximum possible extent. This can be acheieved in two ways. In the first instance, hydro resources, which constitute a non-wasting asset should be developed to the maximum extent possible and sufficiently early. Secondly attention has to be oriented even at the present stage to deriving the full advantages of high efficiencies of thermal power generation which have been attained in the Western countries. The overall thermal efficiency in power stations in this country today of about 20 per cent is less than half the efficiencies currently obtained in the latest installations in foreign countries. Calculated on the basis of present production of about 10,000 million units of thermal energy, an improvement of efficiency of the order of even 1 per cent would save the country, annually about 3,50,000 tonnes of coal. The corresponding figure in 2000 A.D. would be of the order of 4 million tonnes. Steps taken in this direction, would not only husband our limited resources, but aid in economy, by reducing associated overheads on mining and transport of fuel.

All energy losses have to be reviewed. For example, out of the total electrical energy produced a substantial per centage of the order of 15 to 20 is generally lost in transmission and distribution. The position in this respect needs careful study. Steps have to be taken to reduce these to the minimum possible extent, consistent of course, with sound economy.

The steady march of population requires us to consider whether even the known resources of thorium would sustain the country's energy requirements for an indefinite period. It would appear that these also have important limitations in relation to the country's vast future requirements and that alternative sources of energy production, i.e., by controlled fusion, use of solar energy, improved methods of direct electricity production in "Fuel cells" magneto hydro-dynamic generators, etc., have to be fully and thoroughly explored during the next 3 or 4 decades. Research programmes in these fields would have to be initiated and important contributions made by our scientists and engineers.

Some of the other problems attendant on such large scale production of electricity require careful consideration. It is obvious that such programmes of development can be sustained only on the basis of indigenous manufacture of all the components required for transport, transmission and utilisation. On the generating plant side, the annual output of manufacturing industries would have to be increased to about 25 million kW, which involves a four-fold increase over the figures expected to be achieved by 1975 from the factories now being set up at Bhopal, Ramachandrapuram and Hardwar. These should be well within accomplishment, since the country has or can develop practically all the basic raw materials of special iron and steel, insulation, etc., with the possible exception of copper, for which special substitutes may have to be considered. The annual transformer production capacity, required for main as well as distribution transformers, would be roughly of the order of 150 million kVA which requires approximately 1,50,000 tonnes of steel most of which will be of special quality, 75,000 tonnes of copper, etc., on the basis of present designs.

It is in the realm of transmission and distribution that problems of magnitudes begin to become overwhelming. It is already apparent that with the pre-occupation of providing essential power station capacities, necessary attention has not been given to augmenting and strengthening the main transmission, and more specially, the distribution systems. The main transmission systems

have to be sufficiently reinforced for only then can power generating facilities be utilised to the fullest possible extent and at utmost economy. In regard to distribution also, it is quite obvious that in all the important urban centres, distribution systems are relatively inadequate.

On a rough assessment, projecting the experience on some industrially advanced countries whereas in India, fairly long transmission distances are involved, it is expected that by 2000 A.D. we would require approximately 7 million kilometers of main and sub-transmission lines and low voltage distribution systems, of which about 5 million kilometers comprise low voltage distribution lines and about 2 million kilometers representing the main and sub-transmission lines. Against these the present distances in India are about 20,000 kilometers and 150,000 kilometers respectively. The steel and aluminium requirements for transmission lines alone by 2000 A.D. would be of the order of 15 to 20 million tonnes and 1 to 1.5 million tonnes annually. These are very large figures compared to present use of steel and aluminium for these purposes and it is quite obvious that considerable research and special studies would have to be carried out to determine designs which would require the minimum use of raw materials. Colossal investments would therefore be required both for main transmission and for distribution.

While it would be seen from the foregoing that in terms of raw materials and resources, it would be possible for the country to sustain the massive programme of electricity development required by the end of the century, the bottleneck on actual development might well crop up on the front of personnel requirements. Already, electricity development is hampered by shortage of technical personnel extending right through the category of personnel competent to undertake the complex work of research, planning and designs down to the level of skilled operating personnel needed to maintain the expensive power stations and transmission and distribution facilities

(iii) Steel

Steel is considered a smybol of economic potency and consequent prosperity of a country. This it is, in spite of recent development of alternative materials. It is a notable coincidence that up to a limit, the steel output runs paralled to the power output. Thus in Japan, steel production is 24 million tons, while the installed capacity is 25 million kW.

At present, we are producing about 4 million tons and importing about one million tons of steel as compared with the world's production of steel of 354 million tons in 1961. This has to be increased to 50 million tons in 1980, and to about 75 million tons at least at the end of the century. The iron ore required to manufacture steel of this order will be about 150 million tons, compared with the 10 million tons at present, of which we are exporting about 35 per cent.

The total estimated reserve of iron ore in India is of the order of 21,579 million tons, of which 6,790 million tons have been proved. At the rate of consumption at the end of the century, the proved reserves will last for about half a century, while the total estimated reserves may last us for another 100 years.

(iv) National income

In order to determine a goal for our per capita income, it will be worthwhile to have a look at the per capita income and structure of national income of other countries. Tables I and IV give the relevant figures. From the tables it is evident that Japan has a per capita income five times and Yugoslavia three times, that of India. If we target for 2000 A.D. the present per capita level of Japan, it means that relative to the rate of population increase, the rate of national income must be five times and the total increase will be ten fold.

A ten-fold increase in national income during a period of 40 years is equivalent to a compound interest growth at the rate of 6 per annum. In order to see the direction of effort needed, a rough sectoral break-up of national income in 2000 A.D. is estimated and given in Table IV. If the break-up is taken as a target by itself, maximum growth rates are needed in industry and constructional sectors followed by mining and quarrying and transport and communications. These are sectors particularly requiring engineering effort at various levels. Table V gives the projections of the industrial demands in 2000 A.D.

Conclusion

This broad and basic picture of the needs of India of tomorrow, only 35 years ahead of us is *alarming* and indicates that we should make a bold and radical approach to our problems.

Mainly, the problems resolve themselves into two vital issues. We have to positively control our population growth. Secondly for raising the economic edifice, we have to adopt a basic remedy. Recent history has shown, as in Japan and Germany after the last war, the capital is not so very important as technical knowledge and skills in the nation. Once we have built up the technical knowhow within the country, prosperity will automatically build itself. Thus what we urgently, immediately need today is a relentless restriction on population growth and a reservoir of technical manpower. Only then we can ratify our political independence by economic liberation.

If eternal vigilance is the price of liberty, endless effort is the price of progress.

NOTE.—The article is reproduced from the Seventh Sri M. Viswesvaraya Lecture delivered by Dr. K. L. Rao on the occasion of the 44th Annual Convention of the Institution of Engineers (India), Andhra Pradesh Centre, Hyderabad-4, on 9th February 1964.

TABLE I

GROWTH OF ECONOMY IN THE LAST FOUR DECADES IN U.S.A., U.S.S.R. AND JAPAN.

Item.	Unit.	*Countries.* U.S.A. Earlier Value. Year.	U.S.A. Earlier Value. Value.	U.S.A. 1960 Value.	Japan. Earlier Value. Year.	Japan. Earlier Value. Value.	Japan. 1960 Value.	U.S.S.R. Earlier Value. Year.	U.S.S.R. Earlier Value. Value	U.S.S.R. 1960 Value.	India. 1960 Value.
POPULATION ..	Million–Total ..	1920	107	179	1920	55	93	1920	358	212	433
National Income—	1,000 Million–Total.	1929	88	412	1920	2,650 Yen	11,474 Yen	1928	25·0 Roubles	157 Roubles	142 Rs.
	Amount per capita.	1929	721	2,281	1920	47,834 Yen	123,110 Yen	1228	145 Roubles	720 Roubles	328 Rs.
Food Production—											
Rice	Metric ton per 1,000 people.	1934	6.3	14	1934	76·5	173	1948	1·04	0.87	119
Wheat	Do. ..	1928	207	204	Average of (1934–38)	18·9	16·4	1928	128	299	24
Potato	Do. ..	1930	76	65	Do.	23·8	38·6	1928	270	393	6·2
Industries—											
Coal	Metric ton per 1,000 people.	1928	4,337	2,167	1928	546·1	548	1928	209	1,746	122
Crude petroleum ..	Do. ..	1928	1,025·7	1,926	1928	4·2	5·6	1928	66·7	688	1·0
Cement	Do. ..	1928	252·7	310	1928	56·0	242	1928	11·1	212	18·1
Crude steel	Do. ..	1921	185·3	498	1928	30·7	238·0	1928	24·7	304	7·6
Power—											
Installed capacity ..	KW per 1,000 pepole.	1930	334·3	1,028	1930	70·44	254	1948	78·3	311	12·9
Production	KWh per 1,000 people.	1930	941,251	4,657,532	1930	245,853	1,238,970	1930	28,449	1,360,700	46,300
Transport—											
Railways	Passengar KM per 1,000 people.	1930	351,365	189,600	1930	311,033	1,749,900	1928	142,442	795,200	180,700
	Net ton KM per 1,000 people.	1930	4,575,792	4,624,400	1930	170,595	563,600	1928	543.023	7,008,700	167,400
Motor vehicles ..	Passengar cars per 1,000 people.	1928	176·8	342	1937	0·5	4·5	1932	0·0002	0·65	0·66
	Commercial vehicles per 1,000 people.	1928	26·6	67·6	1937	1·22	14·4	1932	0·13	2·3	0·57
Shipping	Gross tons per 1000 people.	1935	95·4	138	1930	67·6	74·4	1948	10·8	15·8	2·0
Civil Aviation ..	Passengar KM per 1,000 people.	1937	5·8	346	1929	0·02	11·3	..	..	..	0·26
	Cargo Ton KM per one million people.	1937	25	6032	1929	0.03	174	..	..	..	82
Higher Education—											
Institutions	No. per million people.	1945	13	11	1947	6	6	1915	0·7	3	-
Students enrolled ..	No. per 1,000 people.	1945	13	18	1947	5	8	1915	..	11	.
Health—											
Physicians and Dentists.	No. per 1,000 people.	1950	1·9	1·6	1950	1·1	1·4	1913	0·18	1·90	0·2
Irrigation—											
Area cultivated ..	1,000 acres–Total.	1920	490,686	717,322 (1959)	1920	14,911	15,177	..	..	55,915	32,000 (1957–58)
Area irrigated ..	Acre–Total ..	1920	12,339	17,786 (1959)	1920	19,192	..	..	..	..	5,800 (1957–58)

TABLE II.

Land Utilization Pattern in India for the Present and the Future.

Classification	Area (million acres.) 1958–59	Area (million acres.) 2000	Percentage Distribution 1958–59	Percentage Distribution 2000
(1)	(2)	(3)	(4)	(5)
Total Geographical area according to village paper*	726	726	100·0	100.0
1. Forest	130	150	17.9	20.7
2. Not available for cultivation—				
(a) land put to non-agricultural uses	34	60	4.6	8.3
(b) barren and uncultivable land	81	66	11.2	9.0
(c) total	115	126	15.8	17·3
3. Other uncultivated land excluding fallow land—				
(a) Permanent pastures and other grazing lands	32	45	4.5	6.2
(b) land under misc. tree crops and growers not included in net area sown	14	30	1.9	4.1
(c) cultivable waste	51	—	7.0	
(d) total	97	75	13.4	10.3
4. Fallow lands—				
(a) fallow lands other than current fallow	30	—	4.2	
(b) current fallows	30	38	4.1	5.2
(c) total	60	38	8.3	5.2
5. Net area sown	324	337	44.6	46.5

* Area according to Surveyor-General -806 million acres.

TABLE III.

Present yields and future requirements of Agricultural Products in India.

Item.	1961. Area in million acres.	1961. Production in million tons.	1961. Average yield in lb. acres	2000 A.D. Area in million acres.	2000 A.D. Production in million tons.	2000 A.D. Average yield in lb. acres
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Foodgrains	280	81.5	652	320	200	1400
Oil seeds	33.6	6·7	447	50	23	1030
Cotton	18.9	5.1 (bales)	106	30	18	235
Jute	1.5	4.0 (bales)	1067	5	16	1280
Sugarcane (Gur)	5.8	80	3090	10	230	5152
Vegetables	3.0	6	4480	5	20	8960
Potato	1.0	2	4480	5	20	8960
Fodder	—	—	—	12		—
Total ..	343·8	—		437	—	—

Note.—These figures include double cropping.

TABLE IV.

Sectoral Break-up of National Income for Various Countries in 1960 and Estimates for India for 2,000 A.D.

	India. 1960–61.	India. 2000.	Canada 1960.	France 1960.	Italy 1960.	Japan 1960.	U.K. 1960.	U.S.A. 1960.	Yugoslavia 1960.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
I. P.C. National Income by Industrial Origin—									
1. Agricultural, forestry and fishing.	48.7	27.6	7.0	10.0	17.0	15.0	4.0	4.0	26.0
2. Mining and Quarrying	1.1	1.7	4.0	2.0	1.0	2.0	2.0	1.0	
3. Household Industry ..	5.5	7.2	29.0	39.0	35.0	40.0	40.0	32.0	44.0
4. Manufacturing ..	9.3	23.3							
5. Construction ..	2.4	10.3	7.0	6.0	7.0	6.0	6.0	6.0	7.0
6. Transport and Communications.	4.9	5.2	9.0	6.0	7.0	*	8.0	6.0	7.0
7. Trade and Commerce	11.5	12.1	14.0	12.0	9.0	16.0	13.0	17.0	11.0
8. Others service ..	12.9	10.3	30.0	25.0	24.0	21.0	27.0	34.0	5.0
9. House property ..	3.7	2.3							
Total at factor cost ..	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100·0	100.0
II. Per capita income (Rs.)	326.0	1,610.0	8,423.0	5,498.0	2,698.0	1,600.0	5,538.0	10,629.0	989.0

* Included under manufacturing.

TABLE V.

Estimates of Industrial Production in 2,000 A.D.

Serial number and Industries.	Unit.	Production 1960–61.	Estimated Production 2000–01.
(1)	(2)	(3)	(4)
1. Steel (Finished)	1,000 ' tons.	2160	75000
2. *Basic Chemicals*—			
2.1 Sulphuric Acid	,,	355	12100
2.2 Caustic Soda	,,	97	1400
2.3 Soda Ash	,,	142	2500
2.4 Cement	,,	7692	88000
2.5 Paper and Paper Board	,,	338	9900
2.6 Glass and Glass Ware	,,	171	3200
3. *Heavy machinery other than electricals*—			
3.1 Steam-boilers	Rs. crores	0.5	320
3.2 Power-driven pumps	Million Nos.	0.102	2.698
3.3 Industrial Machines (Others) ..	Rs. crores	54.0	10946.0
4. *Electrical Machinery*—			
4.1 Transformers	Million kVa.	1.248	150.00
4.2 Hydraulic and Steam turbines and alternators.	Million kW.	—	25.0
4.3 Motors	,,	0.800	69.200
4.4 Others	Rs. Crores.	31.0	4970.0
5. Machine Tools	,,	6.004	435.0
6. *Light Industries*—			
6.1 Radio receivers	Million Nos.	0.267	5.100
6.2 Sewing Machines	,,	0.296	10.700
6.3 Electric Fans	,,	0.991	41.000
6.4 Power-driven pumps	,,	0.102	2.700
7. *Other industries including rural Industries*—			
7.1 Wheat flour	Million Tons.	0.900	11.000
7.2 Sugar	,,	2.436	19.600
7.3 Coffee	,,	0.054	0.450
7.4 Tea	Million Lbs.	986	1400
7.5 Veg. oil product	Million Tons.	0.324	6.700
7.6 Soap	,,	0.139	2.100

FOUNDATION PROBLEMS IN VERTICAL JOINTS

BY

Sri A. N. RAJU, B.E.*

The soil on which a building is founded is sometimes uniform with the same bearing capacity, throughout the length and width of the building. Many a time it is noticed that it is not so. In the latter case the resistance to the settlement at the foundation is not uniform resulting in unequal settlement of the building and creating strain in the various structures of the building.

In actual practice this settlement is observed by providing basement plugs at various points and observing the variation in the levels of all the plugs periodically. The settlement of the building goes up to 2 inches in a year and varies from one corner to another. In addition to the different bearing capacity of the soil, the varying loads transmitted by the structures of the building also add to the unequal settlement. It causes vertical and angular cracks in the walls, linear cracks in the roofs and other dangerous failures in the structures.

To counter act this, vertical joints are provided in buildings normally at every 100'-0". A vertical joint is the one which cuts the building clearly into two from the top of the parapet to the bottom of the concrete in a dead vertical direction for the entire width of the building. Not one part of one half is in structural connection with the other half. The gap between the faces of the joints is treated with mastic or lime mortar. This allows a free movement or settlement of one portion independent of another. The positions of these vertical joints are so selected that the unevenness in the floors and other members because of different settlements are not noticed in actual use. A place adjoining a cross wall will be ideally suited for the vertical joints. Always this position will not be avaliable.

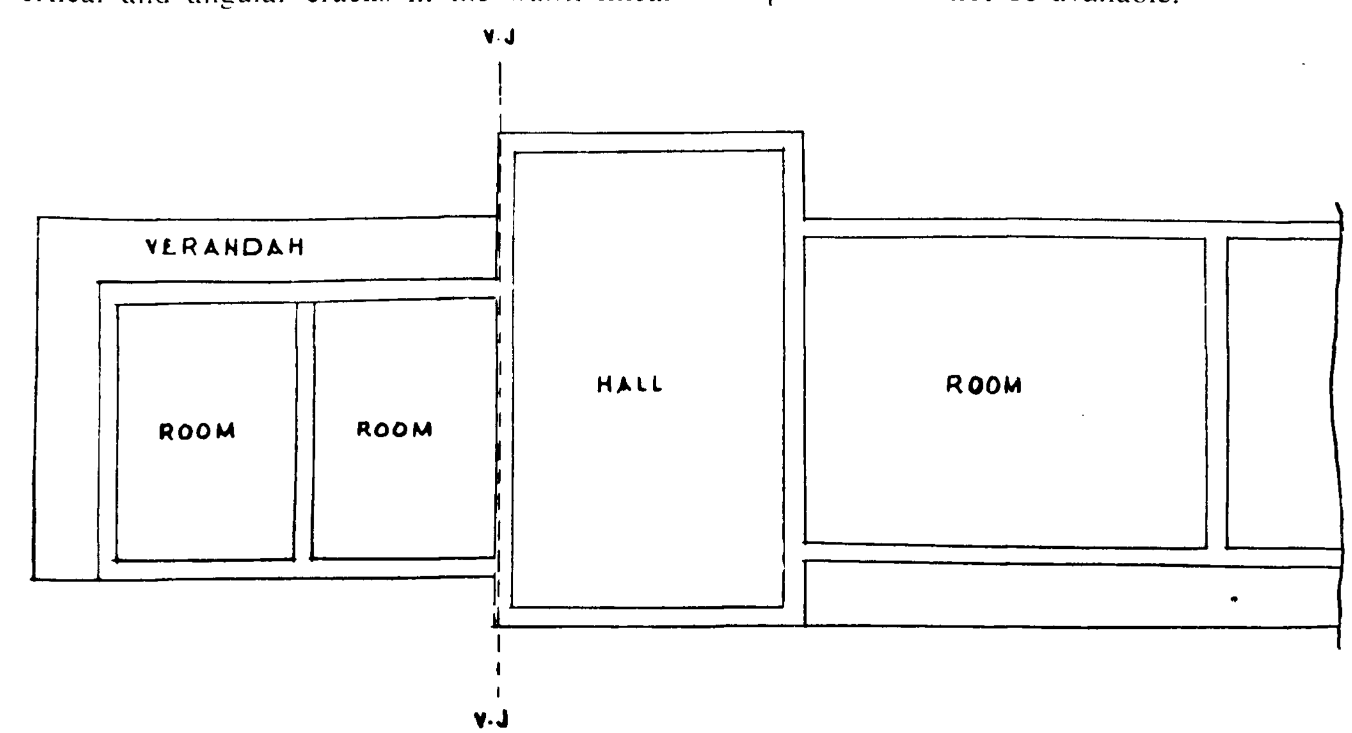

FIG. I

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By providing two-Ell beams in place of a Tee beam and twin columns in place of a single column the vertical joint is made easy. Though it is possible to cut across a slab by making it act as a cartilever it is not usually done.

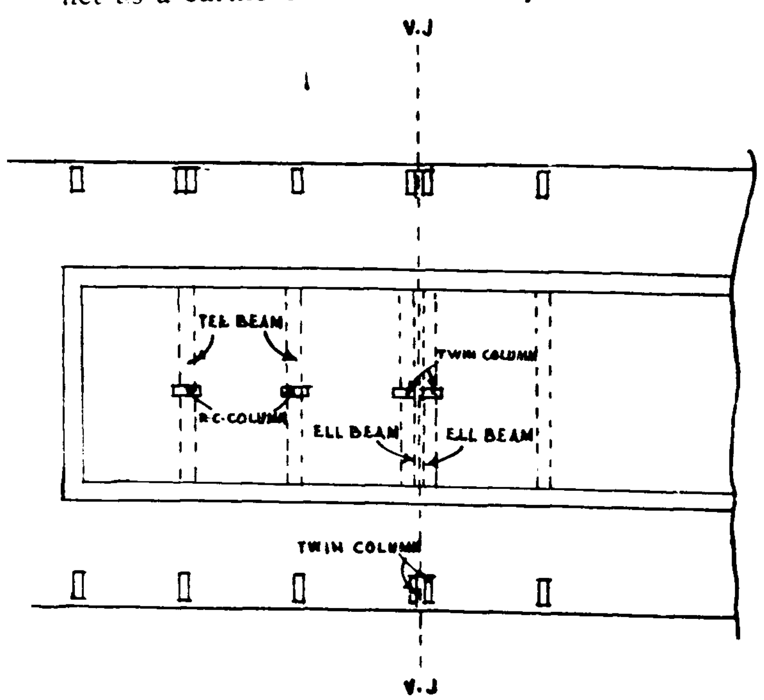

FIG. II

In a single column the load is transmitted to soil uniformly The column footings are designed to pass a load the soil can bear. By the introduction of a twin column, eccentric loading is induced and the intensity of pressure is increased. As the load coming down the column is very great when compared to the weight of the column the resultant force will be very close to the centre line of the column. If not properly dealt with the soil will give way.

The effect of the eccentric load will not change if two loads of equal magnitude and opposite in direction are applied at the centre of the footing. All these will form a concentric load of the same magnitude and a turning moment equal to the product of the same load and eccentricity. The pressure varies from a minimum of 'p_2' at the toe to 'p_1' at the face. The stresses induced by the turning moment at the two edges are equal to $\frac{MY}{I}$. The moment of inertia of the section is

$$\frac{bl^3}{12}$$

Where 'b' is the breadth and 'l' is the length in the plane of bending.

Let 'W' be the resultant load and 'e' is the eccentricity of the load. The foundation is subjected to a concentric load of 'W' and a turning moment of W x e. The pressure at the two extreme edges of the foundation are:

$$\frac{W}{bl} + \frac{MY}{I} = \frac{W}{bl} + \frac{We \times l/_2}{bl^3/12}$$

$$= \frac{W}{bl} \times \left[1 + \frac{6e}{l}\right]$$

When 'e' is less than $\frac{1}{6}$ the intensity of pressure at the inner edge is less than twice the average pressure.

When 'e' $\frac{1}{6}$ the pressure at one end is 0 and at the other end, it is equal to twice the average pressure.

But in the twin columns 'e' is always greater than $\frac{1}{6}$. Very often it comes very near $\frac{1}{3}$

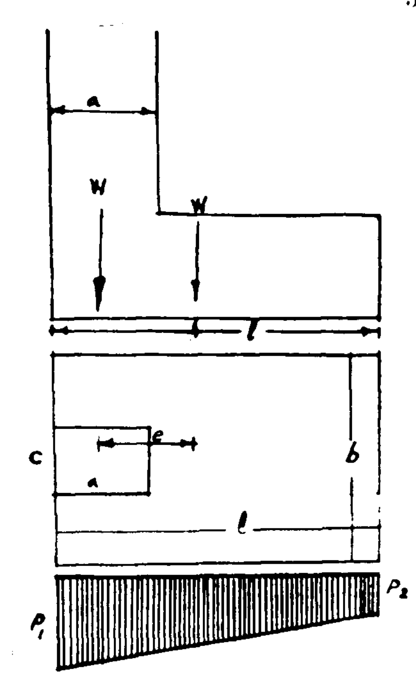

FIG. III

Pressure diagrams

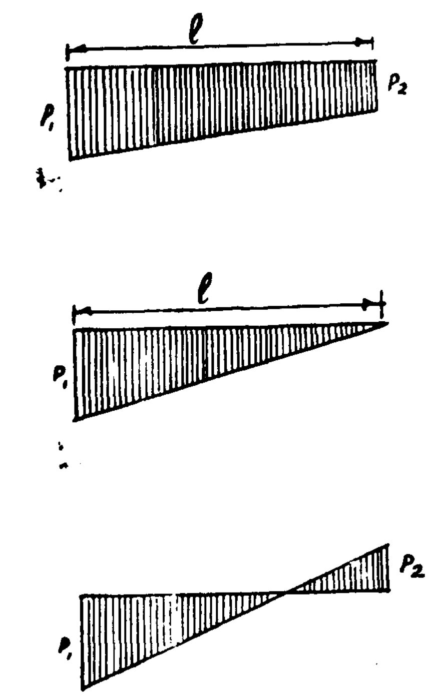

FIG. IV

When 'e' is greater than 1/6, pressure P_2 is tension. Obviously there cannot be any tension induced on the concrete block from below. For a certain length the foundation area on this edge will be relieved of the load. Therefore the entire load will fall on the remaining length. This length can be found out.

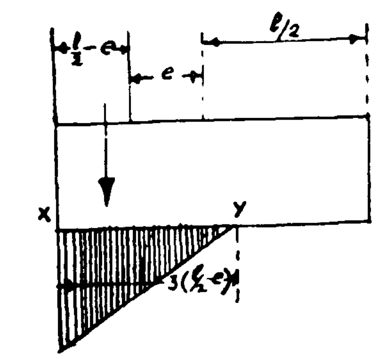

FIG. V

The pressure at y= O. The length 'xy' so adjusts itself that 'W' acts always at the extreme edge of the middle third.

Therefore 'xy' $=3(l/_2—e)$

Again (l/2—e) is the distance from the face to the point at which the resultant of column load and weight of footing pass through.

The intensity of pressure $p_2 = \frac{2W}{3(l/2-e)b}$ If the eccentricity 'e' is l/3 as often it happens the intensity of pressure becomes 4 times the average pressure. This is dangerous because the factor of safety normally adopted for soils is only 3. In poor soils this will cause failure of foundations.

The intensity of pressure may be reduced by increasing the 'l' and 'b' in the formula $\frac{2W}{3(l/2-e)b}$ By increasing the 'l' the point of application of the resultant loads is shifted a little which is not significant. It is to be noted that 'e' also increases when 'l' is increased. By increasing 'b' the pressure can be reduced. But the width 'b' will have to be increased four times to bring down the pressure to the average one. The increase of 'b' has a limited scope.

The other way is to transmit the load from the column to the full length of the column footing. This can be done by spreading the column thickness at the bottom as shown in the sketch.

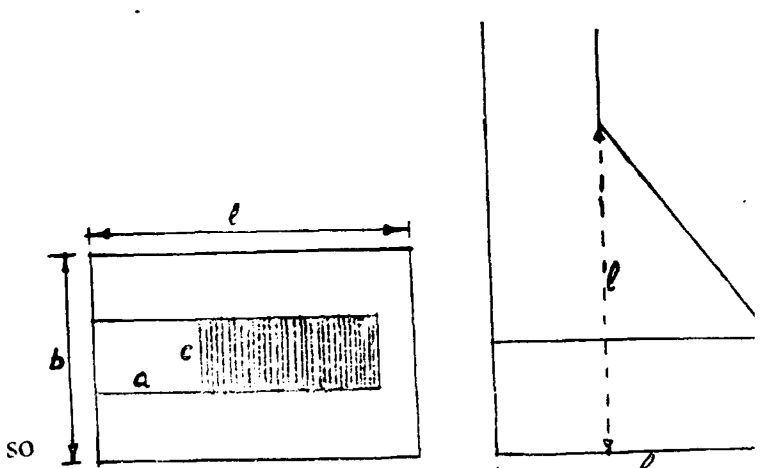

FIG. VI

By the method shown in the sketch the load coming down the column will be dispersed to the full length of the footing, and the pressure will be uniform on the soil. The extra cost involved is negligible.

This method combined with the increase of the front edge of the footing will be more effective. An example illustrating the above principle is given below:

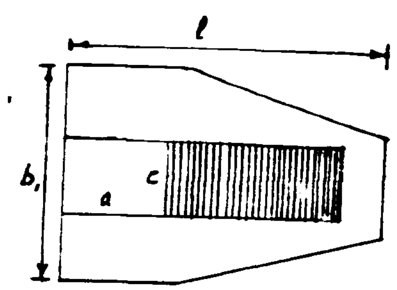

FIG. VII

According to the pressure calculations the load transmitted in one of the Twin columns at the vertical joint is 97,800 lb. or 43.66 tons. The footing rests on a very compact gravel. Allowing 8 tons pressure on the soil the area of base of the footing required is 5.5 square feet. The effective width of the footing in function is $3 \times 4\frac{1}{2}'' = 1'-1\frac{1}{2}''$.

The total length of footing required is 5'. Actually the footing is rested on concrete of 1:4:8 with 1'—0" offset. By splaying the column from a point below the floor level the pressure will be dispersed over the entire area of the base.

The pressure on the soil then works out to

$$\frac{43 \cdot 66}{20} = 2 \cdot 2 \text{ tons/s.ft.}$$

By judiciously adopting these methods according to the field conditions much trouble that may crop up in the future can be avoided which otherwise would be too hard to mend.

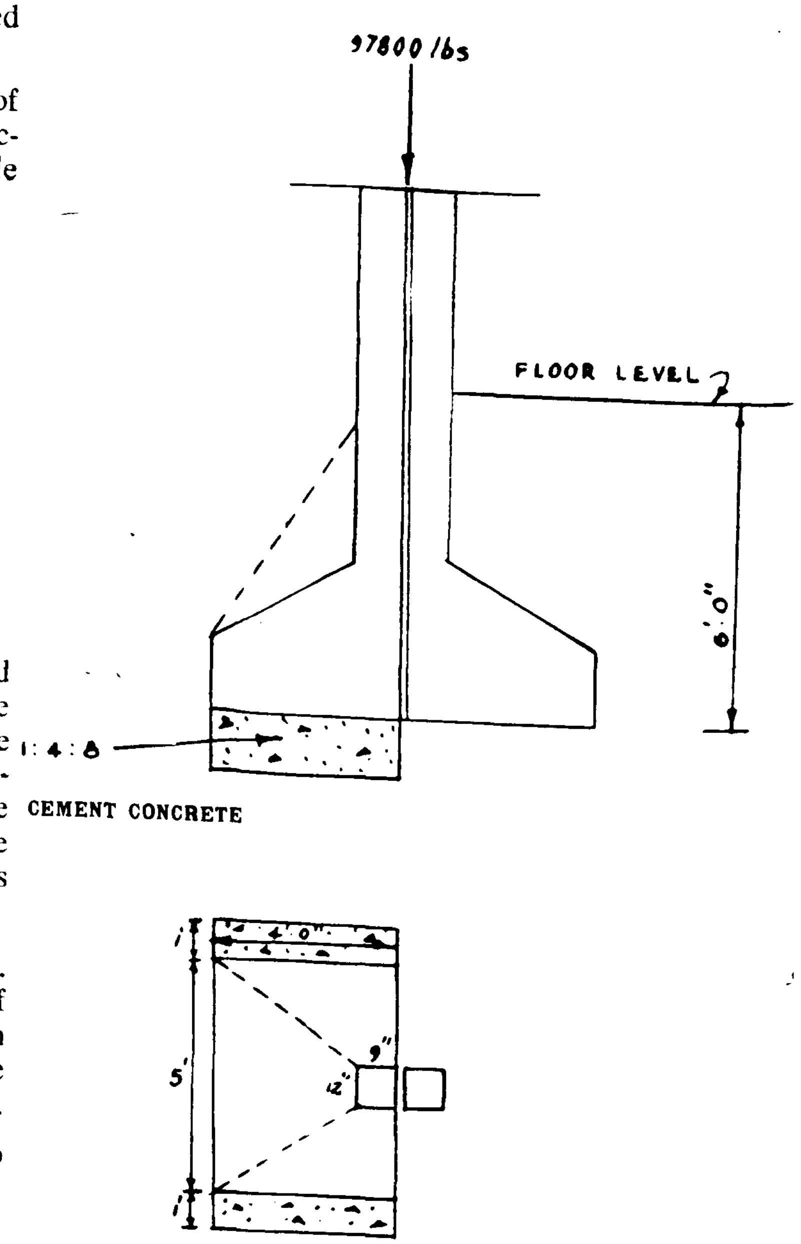

FIG. VIII

THE PRACTICAL DESIGN OF FOUNDATIONS FOR STRUCTURES-FOOTINGS

BY

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Synopsis

The main principles governing the design of foundations for various structures are explained in a set of articles. The present article deals with footing foundations while a subsequent article will deal with pile foundations. The experience of the Madras Laboratories in conducting over a hundred field load bearing tests and the data accumulated so far are presented, so as to help field engineers in the proper choice of the bearing capacity to be adopted in foundation designs where similar soil conditions are met with. The various factors affecting bearing capacity are discussed and guidance on how to use these factors in the field in solving particular problems is furnished. Certain tentative norms are proposed for adoption in the preliminary investigations for foundation design.

Introduction

Madras State is now passing through a stage of rapid industrial development. In addition, the acceleration of the tempo of providing various public utility services, such as hospitals, water supply schemes, etc., has now led to the design and construction of a large number of heavy structures. The engineers of the state have successfully tackled the works so far and are confident of tackling bigger and more complicated works in the coming years with the experience gained so far.

In the design and construction of any big structure, the first and foremost item to be tackled is the site exploration to decide upon the suitability of the site from the point of view of a safe and economic design for the foundations of the structure. Once the site is chosen a detailed study of the site conditions is made, and the economics of various alternatives are worked and then a final choice is made among one of the following types of foundations:—

(1) Strip foundation
(2) Individual footings
(3) Raft foundation
(4) Pile foundation.

The structural function of any of these foundations is to transmit and distribute the loads on the walls, columns, etc., on to the supporting soil mass. As the erection of the structure transmits certain loads to the soil mass, the stress conditions in the soil mass are altered and in general due to this cause, all structures will be subjected to a certain amount of settlement. A proper design for the foundation is therefore aimed at ensuring that the settlements do not exceed such a magnitude as will cause distress to the structure, and that the stress conditions in the soil mass are not increased to such an extent as to cause a general or local failure in the affected area. Therefore, as a first step in foundation design, it is necessary to estimate the bearing capacity of the soil layer which is to support the structure, and as the next step estimate the settlements that may be expected when once the full loads are applied.

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TABLE I.

MAXIMUM SAFE BEARING CAPACITIES HAND BOOK FOR BUILDING ENGINEERS BY NATIONAL BUILDING ORGANIZATION.

Serial number. (1)	Type of Rocks and soils. (2)	Maximum Safe Bearing Capacity Tonnes sq.m. (3)	Remarks. (4)
I. Rocks.—			
1	Rocks-hard without lamination and defects e.g., granite, trap and diorite.	330	..
2	Laminated rocks (e.g. sand, stone and lime stone) in sound condition.	165	..
3	Residual deposits of shattered and broken bed rock and hard shale, cemented material.	90	..
4	Soft rock .. .. .. —	45	..
II. Non-Cohesive soils.—			
5	Gravel, sand and gravel, compact and offering high resistance to penetration when excavated by tools.	45	..
6	Coarse sand, compact and dry	45	Dry means that the ground water level is at a depth not less than the width of foundation below the base of the foundation.
7	Medium sand, compact and dry	25	..
8	Fine sand, silt (dry lumps easily pulverised by the fingers) ..	15	..
9	Loose gravel or sand gravel mixture, loose coarse to medium sand dry.	25	*See* Note.
10	Fine sand, loose and dry	10	..
III. Cohesive soils.—			
11	Soft shale, hard or stiff clay in deep bed, dry	45	This group is susceptible for long term consolidation settlement.
12	Medium clay, readily indented with a thumb nail	25	..
13	Moist clag and sand clay mixture which can be indented with strong thumb pressure.	15	..
14	Soft clay indented with moderate thumb pressure	10	..
15	Very soft clay which can be penetrated several inches with the thumb.	5	..
16	Black cotton soil or their shrinkable or expansive clay in dry condition (50 per cent saturation).	15	..
IV.			
17	Peat	..	*See* Note 3 to be determined after investigation.
V.			
18	Fills or made up ground.	..	*See* Note 3 to be determined after investigation.

NOTE (1).—Increase or decrease in allowable bearing values.

(*a*) The allowable bearing values may be increased by an amount equal to the weight of the material removed from the bearing level, that is the base of the foundation.

(*b*) For non-cohesive soils the allowable bearing value shall be reduced by 50 per cent if the water table is above or near the soil bearing surface. If the water table is below the soil bearing surface at a distance at least equal to the width of the foundation no such reduction shall apply.

NOTE (2).—Compactness or looseness of non-cohesive materials may be determined by driving a wooden picket of dimensions 5×5×70 cm. with a sharp point. The picket shall be pushed vertically into the soil by the full weight of a person weighing at least 70 kg. If the penetration of the picket exceeds 20 cm. the loose state shall be assumed to exist.

NOTE (3).—No generalised values for safe bearing pressures can be given for these types of soils. In such areas adequate site investigations shall be carried out and expert advice shall be sought.

2. Methods for the Determination of bearing capacity.

The different methods currently being adopted for fixing the bearing capacity of a soil stratum can be classified into the following groups:—

(1) Empirical Methods
(2) Semi-theoretical Methods and
(3) In-situ tests.

2.1. *Empirical methods.*—The empirical methods are generally based on the experience of the Engineering profession and evolved by extensive observations. The soils available at the site are studied and based on visual examination or a few identification tests, the soils are classified into a few groups. Judged from long experience on the different types of soils and the behaviour of similar structures erected on such types of soils, numerical bearing values are assigned to these groups.

The most common and widely known example which falls in this category, is the table of allowable bearing values furnished in various building codes. The table of "Safe permissible loads on different soils" prescribed in the M.D.S.S. is well known to all the Engineers of the State. A table of "Maximum Safe bearing capacities" suggested in the handbook for building Engineers in the Metric System prepared by the National Buildings Organisation is reproduced in Table-I for information.

These tables of safe bearing capacities have been severely criticised by many authorities in Soil Mechanics as they do not take into accoun the various factors affecting bearing capacity discussed hereinafter, and also because a prope identification and classification of the soil me with at site is not generally made and used witl these tables. Therefore, the use of the safe bear ing capacity values from these tables should b limited to only very unimportant structures sucl as small temporary buildings, etc.

2. 1.2 *Voids Ratio method.*—This methoc takes into account the physical properties of th stratum such as moisture content, density, etc. a determined from laboratory tests and is a definit improvement over the first method. Thi method has been developed and introduced i this country by the Russian Engineers and i more scientific and can be used in conjunctio with laboratory tests in a semi-quantitative way Still as the bearing capacities are prescribed an fixed arbitrarily, the method has to be classifie as empirical.

To adopt this method for working out the saf bearing capacity, undisturbed samples should b obtained and the following tests conducted—(1 Mechanical analysis, (2) Natural moisture con tent, density and voids ratio, (3) Specific gravit and (4) Atterberg limits.

Soils are divided into three main type (*a*) Rocky, (*b*) Sandy and (*c*) Clayey. If th plasticity index is less than 1, the soil is classi fied as sandy. If more it is classified as clayey Sandy soils are further classified on the basis c physical properties and for each case suitabi bearing values are assigned—Tables II and III

TABLE II.

Nomenclature of Sandy Soil.	Particle size distribution.	Degree of natural composition.		
		Dense.	Medium.	Loose.
(1)	(2)	(3)	(4)	(5)
Gravel Sand ..	Particles bigger than 2 mm. exceed 25 per cent by wt.	e<0·55	e=0·55 to 0·65	e>0.6
Coarse Sand ..	Particles bigger than 0·5 mm. exceed 50 per cent by wt.	Do.	Do.	Do.
Medium Sand ..	Particles bigger than 0.25 mm. exceed 50 per cent by wt.	Do.	Do.	Do
Fine Stand ..	Particles bigger than 0·1 mm. exceed 75 per cent by wt.	e<0·60	e=0·60 to 0·70.	e>0·7
Dust like Sand ..	Particles bigger than 0·1 mm. less than 75 per cent by wt.	Do.	e=0·60 to 0 80	e>0·8

TABLE III.

BEARING CAPACITY OF SANDY SOILS.

Serial number.	Name of the soil type.	Permissible Bearing Pressure in Kg/Cm ². Dense.	Mid-dense.
(1)	(2)	(3)	(4)
1	Gravel, Coarse sand irrespective of their moisture content	4·5	3·5
2	Medium size sand irrespective of their moisture content	3·5	2·5
3	Fine Sand—(a) Slightly wet	3·0	2·0
	(b) Highly wet and Saturated	2·5	1·5
4	Dust Like Sand—(a) Slightly wet	2·5	2·0
	(b) Highly wet	2·0	1·5
	(c) Saturated with water	1·5	1·0

Clay type soils are further divided based on plasticity Index and natural moisture content. Plasticity Index between 1 and 7 is classified as sandy loam, between 7 and 17 as sandy clay and about 17 as clay. If the natural moisture content is less than 1.2 times the plastic limit, it is taken as hard consistancy and greater than 1.2 times plastic limit is referred to as plastic consistancy. The permissible design pressures for various clay soils in different states of consistancy, for various voids ratio can be obtained from Figure-1.

2.2 *Semi-Theoretical Methods.*—These methods of evaluating the bearing capacity have been developed by different authorities based on an analysis of the stress conditions in the soil stratum at the limiting state, just before failure occurs. Assumptions are made regarding the probable shapes of the failure zones, and the ultimate bearing capacity is estimated based on the forces mobilised in the soil mass opposing the deformation induced by the loads. The usual soil constants which appear in these formulae are density (γ). Cohesion (c) and angle of friction (ϕ). For determining these constants laboratory tests on undisturbed samples taken from the site are to be conducted.

The following are a few simple formulae generally used and accepted in the profession. For a more detailed discussion on these formula a reference can be made to special articles on this subject (1) (2).

$$q = \gamma Df \tan^4 (45 + p/2)$$

$$= \gamma Df \left\{ \frac{1 + \operatorname{Sin} \phi}{1 - \operatorname{Sin} \phi} \right\}^2 \quad \ldots (1)$$

$$q = 5.14\, c = 2{\cdot}57\, qu \quad .. \quad (2)$$

$$q = c\, Nc + \gamma\, Df\, Nq + \tfrac{1}{2}\, \gamma\, BN_\gamma \quad (3)$$

where q = ultimate bearing capacity.

Df = Depth of foundation.

qu = unconfined compression strength.

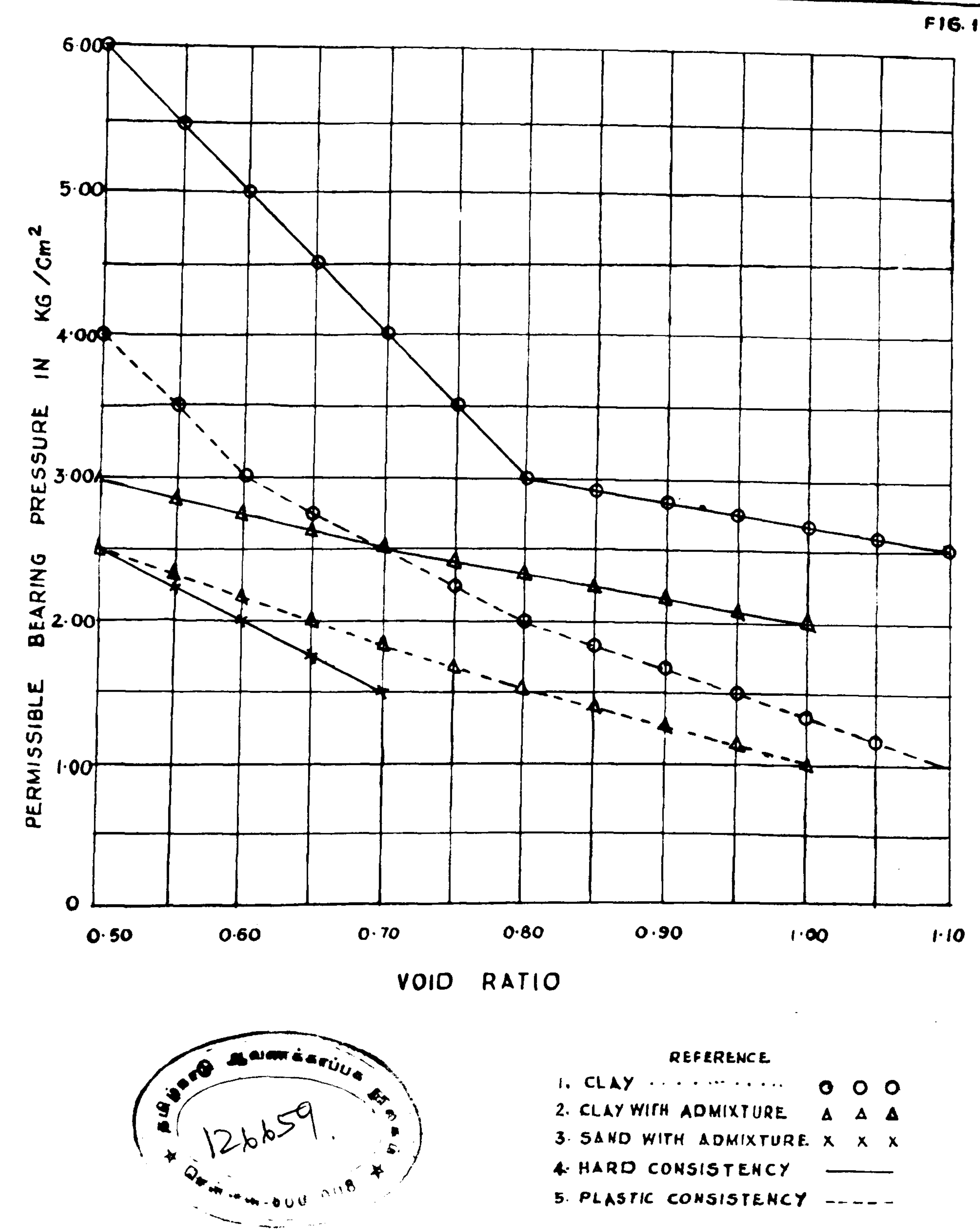
Nc, Nq and N_γ = bearing capacity factors.

Equation (1) is generally referred to as the Rankines formula. This is usually applicable for sandy soils and is generally used by Engineers to check the minimum depth of foundations for buildings.

Equation (2) is applicable to cohesive soils having negligible angle of friction.

Equation (3) is known as Terzaghi's formula and is applicable for shallow continuous footings under general shear failure. Some modifications are prescribed, for local shear failure and when the footings are either square or circular. Values of the bearing capacity factors are also furnished for various values of angle of friction (3).

Errors due to sampling such as, the specimens tested at the laboratory not representing adequately the soils at site, disturbance to the



STANDARD CURVES SHOWING PERMISSIBLE BEARING PRESSURE OF CLAY GROUP SOILS sample during sampling operations, etc., affect the bearing capacity estimates obtained by the use of these formulae. Hence a reasonably high factor of safety is to be adopted when the safe bearing capacity is estimated using these formulae. Also the experience of the Madras Laboratories has been that the values obtained by the use of Terzaghi's formulae gives bearing capacity values somewhat on the high side as compared to the results of in-situ tests (4).

2.3. *In-situ tests.*—Two in-situ tests are usually adopted for evaluating the bearing capacity, viz., penetration tests and plate bearing tests. In the standard penetration test, the standard split barrel sampler is driven into the stratum by a drop hammer of given weight falling through a fixed distance and the number of blows required per foot of penetration is recorded. The number of blows per foot of penetration is correlated with the relative density of the material and also the bearing capacity. Using figure-2 and Table-IV the bearing capacity can be estimated.

2.3. 2. *Plate bearing Tests.*—This is an in-situ test and is carried out at the location at which the bearing capacity is required. The equipment as used in this Research Station is shown in figure-3. The procedure adopted is generally in accordance with standard procedure prescribed in I.S. No. 1888-62 except for the following slight modifications. The loads are maintained constant for one hour or till the rate of increase of settlement is less than 0.02" per hour. This is done mainly in the interest of quickness so that the tests could be completed in one day. Also readings of settlement are taken every five minutes. The load test is conducted till the settlement increases rapidly. The test is taken as completed if the soil fails completely (i.e., no more load can be applied at the site) or if the settlements are excessive (exceeds 1"). A specimen data sheet of readings obtained during a test are furnished in Table No. V. The load settlement curve is shown in figure-4.

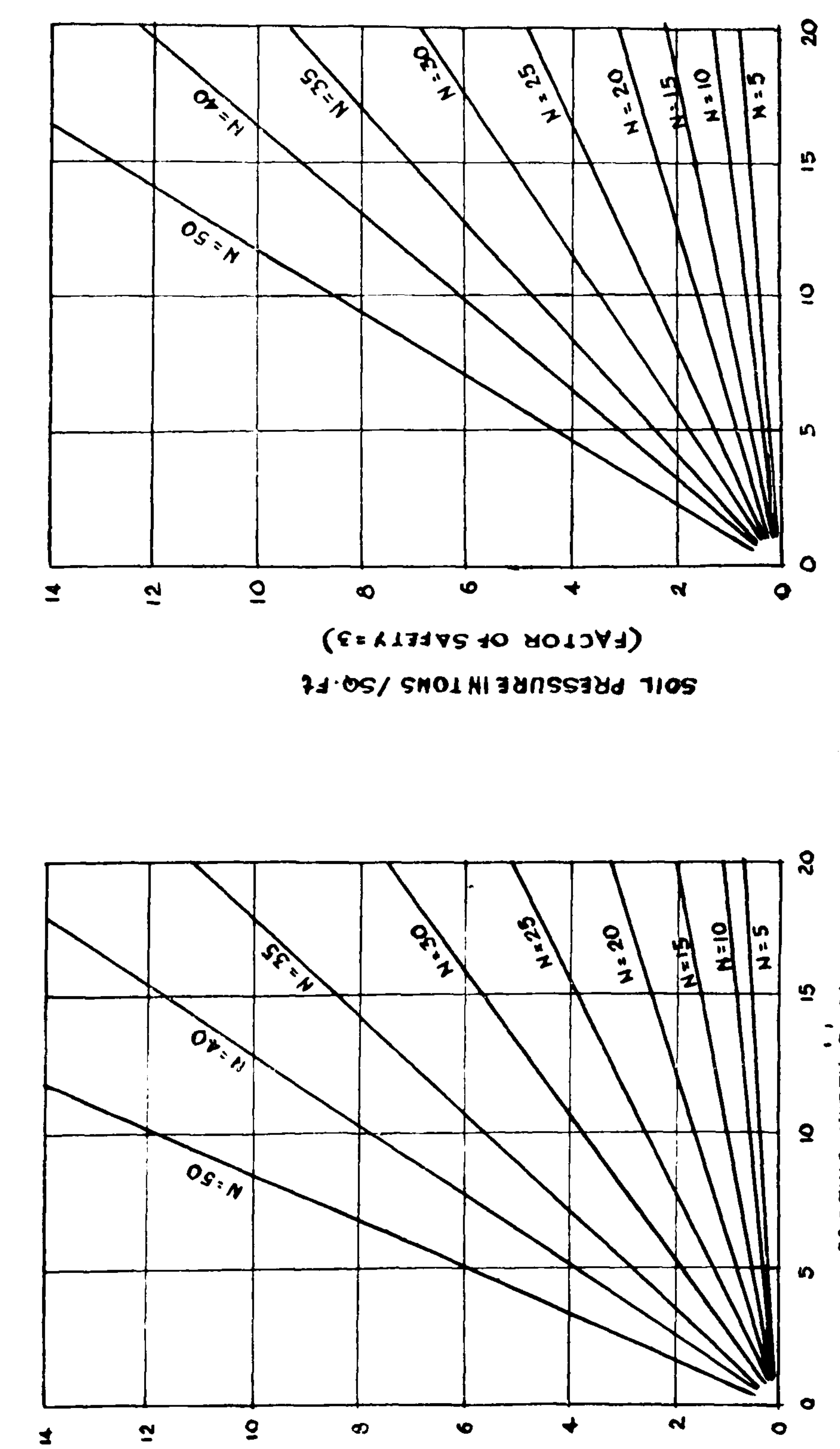
2.3. 3. *Interpretation of Load Test Data.*—The extrapolation of the results of the load test to predict the load-settlement characteristics and bearing capacity for large size footings is a matter which requires a certain amount of judgement in addition to a thorough knowledge of the behaviour of different types of strata. Generally the ultimate bearing capacity is to be taken as the point in the load settlement graph at which the settlement increases rapidly or the point at which the curve again tends to became a straight line in the final stages of loading. In many cases, locating the yield points as per the above criteria is quite a difficult matter, as the point may not be clearly defined. The following two methods are usually adopted in this Research Station and gives satisfactory results.

(*a*) *Log-Log Plot.*—If the data of the load test are plotted in a log-log scale (Figure 4), we get two straight lines intersecting at a point, which is taken as the yield point (ultimate bearing capacity). By applying a suitable factor of safety (usually 3) the safe bearing capacity is obtained.

(*b*) *Housel's progressive settlement method.*—This method is based on the progressive settlement recorded for each load during a load test. In any load test, for the first few increments of load, a large percentage of the settlement for each load takes place as soon as the load is applied. Only a small amount of further settlement takes place in the next few minutes. All but a negligible amount of settlement takes place in the first 20 minutes. For higher loads, the settlement is progressive even after 30 minutes and may extend even beyond the one hour period. The yield point is taken as reached when the settlement is progressive and does not stop within the first 30 minutes.

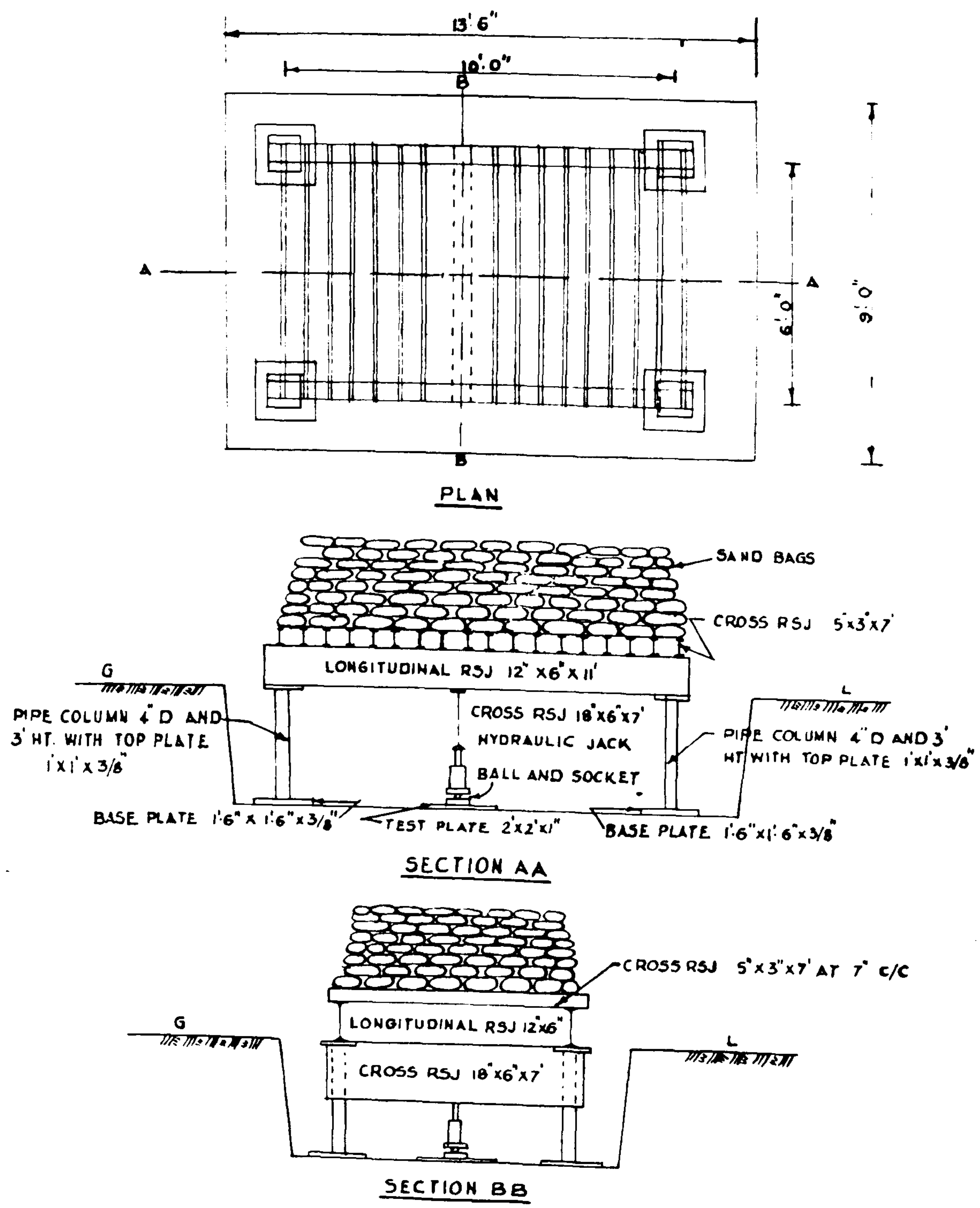
2.3.4. *Limitations of the Load Test.*—In applying the results of the load test to a prototype the following two points should be borne in mind. First, the results of the load test reflect the character of only the soil located within a depth of about twice the size of the bearing plate, whereas the settlement of a footing depends on a much thicker soil stratum, depending on the size of the footing. As a consequence, if the

FIG.2



SAFE SOIL PRESSURES BENEATH FOOTINGS ON SAND AS DETERMINED BY BEARING CAPACITY

FIG 3



LOADING FRAME

20 TONS CAPACITY

character of the soil changes below a depth of about twice the width of the place the test results may be misleading. Secondly in saturated cohesive soils, settlement due to consolidation (forcing out of pore water and corresponding reduction in voids ratio due to applied loads) takes considerable time to be fully developed and this will not be brought out in the short intervals of the loading test.

In addition, the site conditions during a load test may not correspond to the worst conditions that may occur in the field during different seasons, etc. This factor should also be taken into consideration when interpreting load test results.

2.3.5. Field load tests as per the above procedure have been conducted at more than a hundred places all over the Madras State. The locations and results of these tests are furnished in Table VI. The test data herein tabulated may be used as an approximate guide to the probable bearing capacity where similar soil conditions are met with.

2.3.6. *A simplified procedure for determining the bearing capacity at site.*—The standard load test is somewhat expensive and time consuming. Many small constructions may not be able to afford the time and expense for conducting a regular field plate bearing test for determining the safe bearing capacity at site. Still it may be desirable to have a reasonably accurate estimation of the bearing capacity. For such cases, a simplified procedure has been developed by this Research Station.

TABLE IV.

PENETRATION RESISTANCE AND SOIL PROPERTIES ON BASIS OF THE STANDARD PENETRATION TEST.

Sands.		S.B.C. Tons/sq. ft.	Clays.		S.B.C. Tons/sq. ft.
Number of Blows per ft. N.	Relative Density.		Number of Blows per ft. N.	Consistency.	
(1)	(2)	(3)	(4)	(5)	(6)
0–4	Very loose	Less than 0·5	Below 2	Very soft	Less than 0·25
4–10	Loose	0·5—1·0	2–4	Soft	0·25—0·5
10–30	Medium	1·0—3·5	4–8	Medium	0·5 —1·0
30–50	Dense	3·5—6·0	8–15	Stiff	1·0 —2·0
Over 50	Very dense	Over 6·0	15–30	Verystiff	2·0 —4·0
..	..	..	Over 30	Hard	Over 4·0

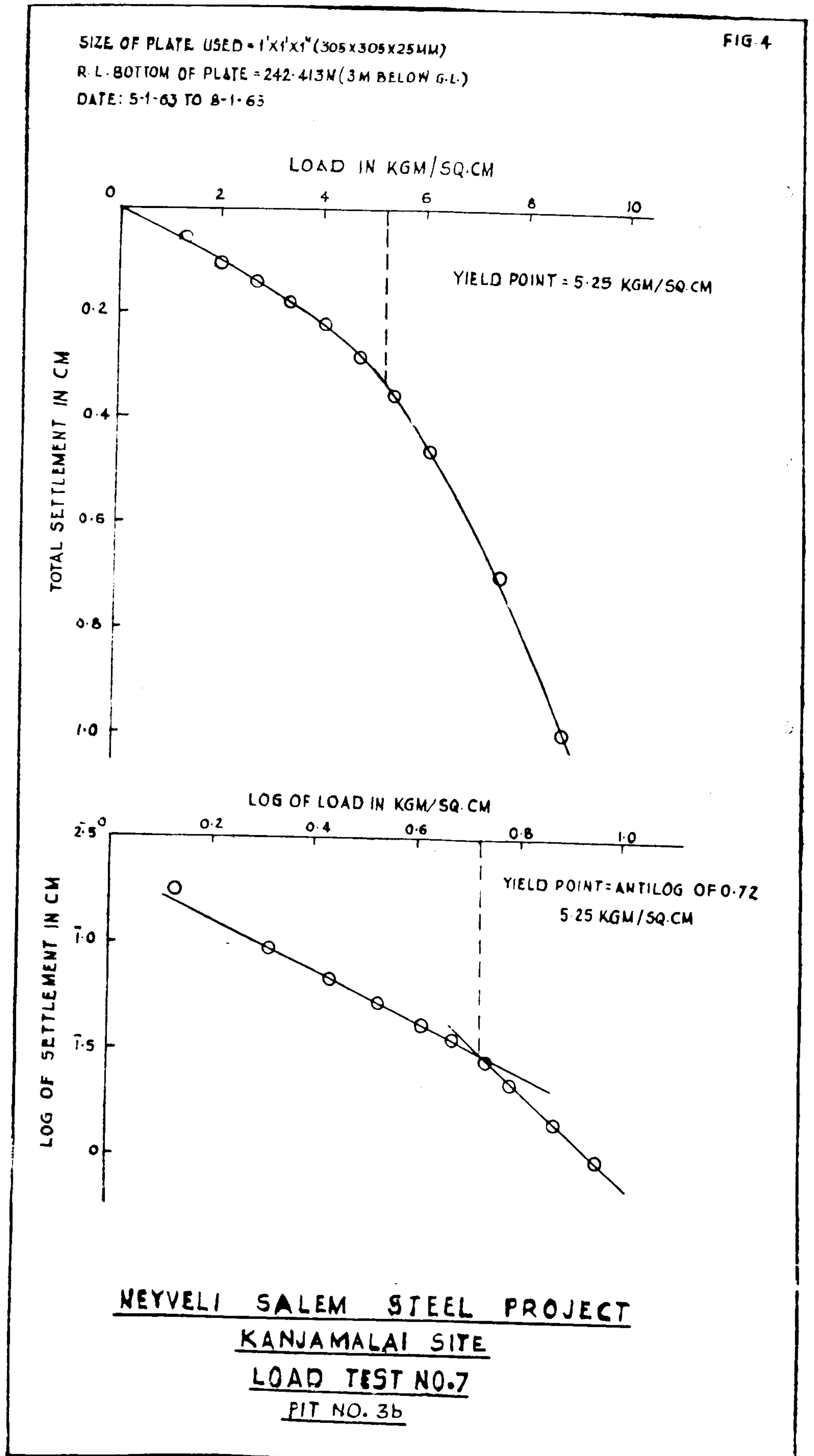
TABLE V.

NEYVELI SALEM STEEL PROJECT.

Load Test No. 7.

Data for log—log plot.

Serial number.	Load in Kgm./Cm².	Settlement in inches.	Settlement in cms.	Log of load in Kgm./Cm².	Log of Settlement in cm.	Remarks.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1·3568	0·022	0·056	0·1332	$\bar{2}$·7472	..
2	2·0352	0·042	0·107	0·3086	$\bar{1}$·0280	..
3	2·7136	0·056	0·142	0·4336	$\bar{1}$·1530	..
4	3·392	0·071	0·180	0·5305	$\bar{1}$·2561	..
5	4·0704	0·0885	0·224	0·6096	$\bar{1}$·3517	..
6	4·7488	0·113	0·287	0·6766	$\bar{1}$·4579	..
7	5·4272	0·139	0·353	0·7346	$\bar{1}$·5478	..
8	6·1056	0·1825	0·464	0·7857	$\bar{1}$·6661	..
9	7·4624	0·2765	0·702	0·8728	$\bar{1}$·8465	..
10	8·8192	0·3935	0·999	0·9454	$\bar{1}$·9997	..



This procedure is based on the correlation discovered between the safe bearing capacity as obtained from a full load test and the observed settlement of the test plate at a load of 2 tons/sq. ft. This procedure was first proposed and discussed at the Annual Research Conference of the Central Board of Irrigation and Power held at Ootacamund in 1962 (4). Based on the discussions at Ootacamund and subsequent conferences, and the comments of experts on this field, the original expression for bearing capacity has been refined and improved and is of the following form.

$$B = 0{\cdot}37\ S^{-0{\cdot}53} \quad \ldots \quad \ldots \quad (4)$$

$$B' = 2 \times S'^{-0{\cdot}53} \quad \ldots \quad \ldots \quad (5)$$

wherein B = Bearing capacity in Tons/sq. ft.

S = Settlement in inches at a load of 2 Tons/ sq. ft.

B′ = Bearing capacity in Tonnes/sq. meter.

S′ = Settlement in Cms at a load of 21·7 Tonnes/ sq. meter.

The actual field procedure is as follows:—

At the site, in question, a square pit of minimum size 6′ x 6′ in plan is dug to the depth at which the bearing capacity is required. A mild steel plate at least ¾″ thick and 1′ square is positioned at the centre of the pit and is levelled. Suitable device for applying a load of 2 tons over this area is arranged. A dial gauge with datum bar, etc., is suitably positioned so as to determine the settlement of the plate. The load of 2 tons is applied and corresponding settlement is determined at the end of one hour after the load is applied. From this observed settlement the bearing capacity can be calculated using the formulae, or may be read off from the curve (Figure 5). The bearing capacity estimate obtained as above is used with a factor of safety of 1.5.

TABLE VI.

Serial number	Location of Test. Pit No.	Location of Test. Depth.	Type of Soil met with.	Lab. No. for sample collected.	Settlement in inches for a load of 2 T/sq. ft.	Safe Bearing Capacity by Log-Log Plot.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			I. Raw Film Factory Site, Ootacamund.			
1.	1	10′-0″	Yellow, red white clay ..	CBI. 943	0·04	1·50
2.	4	10′-6″	Do. ..	,, 950	0·076	0·96
3.	2	20′-0″	Yellow, white Gray clay ..	,, 946	0·15	0·92
4.	5	12′-0″	Red clay	,, 991	0·02	2·20
5.	6	10′-0″	White Gray, light brown and yellow clay.	..	0·06	1·95
6.	3	16′-0″	Do. ..	,, 989	0·10	1·60
7.	7	16′-0″	Do. ..	,, 995	0·06	1·50
8.	8	4′-0″	Yellow, red clay	,, 1024	0·075	1·10
9.	9	5′-0″	Yellow, red & white clay ..	,, 1025	0·064	1·27
10.	4	10′-6″	Yellow, white gray clay ..	,, 950	0·63	0·93
11.	5	12′-0″	Red, Yellow, white clay ..	,, 991	0·0125	2·06
			II. Surgical Instruments Project,, Nandambakkam.			
12.	I	5′-6″	Compacted sand	165/61	0·13	1·67
13.	IV	4′-6″	Do.	2 of 167/61	0·10	1·71
14.	VI	3′-9″	Do.	3 of 167/61	0.115	1·67
15.	V	6′-9″	Do.	..	0·0275	2·23
16.	VII	3′-9″	Do.	9 of 175/61	0·175	1·25
17.	III	3′-3″	Do.	..	0·094	2·04
18.	II	1′-6″	Clay	12 of 181/61	0·29	0·63

TABLE VI—*cont.*

Serial number.	Location of Test. Pit No.	Depth.	Type of Soil met with.	Lab. No. for sample collected.	Settlement in inches for a load of 2 T/sq. ft.	Safe Bearing Capacity by Log-Log Plot.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			III. Teleprinter Factory, Guindy.			
19.	1	6′–3″	Clay	CBI. 849	0·16	0·92
20.	2	7′–0″	Compacted sand	„ 850	0·082	2·00
21.	3	6′–9″	Sand	„ 851	0·066	1·33
22.	4	8′–9″	Do.	„ 852	0·048	1·67
23.	5	8′–0″	Do.	„ 857	0·016	1·90
24.	6	8′–9″	Do.	„ 858	0·034	1·49
			IV. Stanley Hospital Compound, Madras.			
25.	1	6′–0″	Filled up sand	CBI. ..	0·20	0·50
26.	2	6′–0″	Do.	„ 840	1·50	0·38
27.	3	6′–0″	Do.	„ 841	0·44	0·42
28.	4	6′–0″	Do.	„ 842	6·35	0·42
29.	5	13′–3″	Filled up earth	„ 912	1·60	0·21
30.	6	7′–6″	Do. sand	„ 926	0·42	0·50
			V. Heavy Electrical Project, Tiruchirappalli.			
31.	1	2′–0″	Top red soil	..	0·036	3·40
32.	2	6′–0″	Soft disintegrated rock	..	0·016	6·40
33.	3	3′–6″	Hard gravel	..	0·020	4·60
34.	4	8′–6″	Soft disintegrated rock	..	0·010	7·00
35.	5	3′–6″	Do.	..	0·025	6·10
36.	6	3 –6″	Top red earth	..	0·016	1·80
37.	7	4′–0″	Gravel	..	0·012	1·79
38.	8	5′–6″	Soft disintegarted rock	..	0·009	6·80
39.	9	3′–0″	Hard gravel	..	0·024	3·67
40.	10	0′–6″	Top red soil	..	0·090	2·17
41.	11	6′–6″	Soft disintegrated rock	..	0·028	6·00
			VI. Sand Factory, Ennore.			
42.	1	3′-3″	Fine sand	CBI. 730	0·044	1·67
43.	2	3′-0″	Do.	„ 735	0·148	1·00
44.	3	3′–0″	Do.	„ 736	0·27	1·17
45.	4	3′-0″	Do.	„ 737	0·07	1·33
46.	5	2′–3″	Do.	„ 741	0·20	0·92
47.	6	2′–3″	Do.	„ 742	0·32	0·83
48.	7	2′–3″	Do.	„ 743	0·33	0·67
49.	8	2′-3″	Do.	„ 744	0·025	1·00
50.	9	0′–3″	Do.	„ 774	0·125	0·83
51.	10	0′–3″	Do.	„ ..	0·10	1·50
52.	11	0′–3″	Do.	„ ..	0·30	1·00
53.	12	0′–3″	Do.	„ ..	0·37	0·50
			VII. Medical College Hostel Compound, Kilpauk.			
54.	1	2′–0″	Stiff clay	CBI. 843	0·08	1·33
55.	2	4′-0″	Do.	„ 859	0.03	1·92
			VIII. Grant Lyon Site, Red Hills.			
56.	1	3′–0″	Soft clay	CBI. 1149	0·20	0·70
57.	2	5′-0″	Soft clay with sand	..	0·170	0·64

TABLE VI—*cont.*

Serial number.	Location of Test. Pit No.	Depth.	Type of soil met with.	Laboratory number for sample collected.	Settlements in inches for a load of 2T/sq. ft.	Safe Bear capaci by Log-I plot.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			D.M.S. Office Compound, Madras.			
58.	Pit No. 3	6′–0″	Soft clay..	CBI 1150	0·170	0·73
59.	„ 4	6′–6″	Clay with sand ..	CBI 1151	0·100	1·00
			Chepauk Office Compound, Madras.			
60.	„ 1	5′–6″	Sand		0·11	1·02
			Atomic power plant, Mahabalipuram.			
61.	„ 1	4′–0″	Sand mixed with clay	..	0·038	3·82
62.	„ 2	4′–3″	Compacted dense sand	..	0·010	4·33
63.	„ 3	4′–6″	Soft disintegrated rock	..	0·010	6·21
			Phyto-Chemical Project, Neriamangalam, Kerala State.			
64.	„ 1	4′–6″	Lateritic soil	..	0·013	4·10
65.	„ 2	5′–0″	Do.	..	0·009	3·57
66.	„ 3	5′–6″	Yellowish Lateritic soil	..	0·009	4·86
67.	„ 4	4′–9″	Do.	..	0·010	4·93
68.	„ 1 (Extended)	5′–0″	Do.	84/62–1	0·005	3·50
Palakkarai Reservoir site.			*Trichy Water Supply Scheme, Trichy.*			
69.	Pit No. 1	7′–6″	Stiff clay	109/62–7	0·05	1·74
Urayur Reservoir site.						
70.	Pit No. 1	12′–3″	Soft disintegrated rock	109/62–9	0·06	1·28
			School of Arts Building Compound, Madras.			
71.	„ 1	6′–0″	Soft clay	CBI 1294	0·013	0·71
			Neyveli-Salem Steel Project, Salem.			
Kanjamalai site, Salem.						
72.	Pit No. 1 (a)	5′–0″	Weathered rock	2/63–2	0·021	1·19
73.	„ 1 (b)	10′–0″	Do.	2/63–5	0·035	>5·25
74.	„ 2 (a)	6′–6″	Do.	1/63–2	0·018	>1·84
75.	„ 2 (b)	10′–0″	Hornblende Gneiss rock	2/63–5	0·012	>5·5
76.	„ 3 (a)	6′–6″	Hardstiff clay mixed with sand.	11/63–2	0·063	1·5
77.	„ 3 (b)	10′–0″	Dense sand	11/63–4	0·041	1·61
78.	„ 4 (a)	4′–6″	Brown soil with Kankar Lime.	132/62–2	0·138	0·88
79.	„ 4 (b)	7′–6″	Weathered rock	132/62–5	0·024	>1·84
Pallipalayam site.						
80.	Pit No. 1 (a)	5′–0″	Soft disintegrated rock	29/63-8	0·095	0·93
81.	„ 1 (b)	8′–0″	Disintegrated rock	..	0·024	>5·5
82.	„ 2 (a)	5′–0″	Do.	29/63–3	0·029	3·68
83.	„ 2 (b)	7′–6″	Do.	29/63–4	0·016	>5·5
84.	„ 3 (a)	5′–0″	Soft disintegrated rock	23/63–1	0·173	0·73
85.	„ 3 (b)	8′–0″	Disintegrated rock	29/63–6	0·028	5·5
86.	„ 4 (a)	5′–0″	Soft disintegrated rock	23/63–3	0·083	0·86
87.	„ 4 (b)	10′–0″	Disintegrated rock	23/63–5	0·043	2·17

TABLE VI—*cont*.

Serial number.	Location of Test. Pit No.	Depth.	Type of soil met with.	Laboratory number for sample collected.	Settlement in inches of a load of 2T sq. ft.	Safe Bearing capacity by Log-Log plot.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			District Magistrate Office Building, Vellore.			
88.	Pit No. 1	13'-6"	Filled up earth	3/63-1	0·123	0·58
89.	,, 2	13'-6"	Do.	3/63-2	0·175	0·35
90.	,, 2	7'-6"	Filled up with 6'-0" thick sand.	..	0·275	0·58
			Municipal Market site. Vellore.			
91.	,, 1	6'-0"	Filled up earth	36/63-1	0·370	0·568
92.	,, 2	10'-0"	Do.	,, 12	0·539	0·46
93.	,, 3	8'-0"	Do.	,, 2	0·134	0·57
94.	,, 4	8'-0"	Do.	,, 4	0·236	0·56
95.	,, 5	10'-0"	Do.	,, 5	0·130	0·695
96.	,, 6	12'-0"	Do.	,, 6	0·170	0·70
97.	,, 7	10'-0"	Do.	,, 7	0·127	0·57
98.	,, 3	14'-0"	Do.	,, 3	0·153	0·52
99.	,, 8	12'-0"	Do.	,, 8	0·130	0·58
100.	,, 9	12'-0"	Do	,, 9	0·594	0·51
101.	,, 10	12'-0"	Do.	,, 10	0·126	0·62
102.	,, 11	12'-0"	Do.	,, 11	0·105	0·73
			Mechanised Brick Plant, Red Hills.			
103.	,, 1	6'-6"	Sand	CBI 1142	0.04	1·42
104.	,, 2	5' 9"	Do.	CBI 1143	0·075	1·09
			The Hindu Theological High School Buildings Compound, Madras.			
105.	,, 1	6'-0"	Dense sand	..	0·124	1·6

This procedure is quite safe and relatively simple, and can be adopted for medium sized structures, where the use of the full load test is not warranted. It may be noted that the limitations of the full load test already mentioned in paragraph 2.3.4. apply to this simplified load test also.

3. **Factors affecting bearing capacity**—We have so far seen how the bearing capacity at any site can be determined. The following are the other main factors to be considered when studying the variation of bearing capacity of any particular site—

(*a*) Depth of foundation.

(*b*) Size and shape effects.

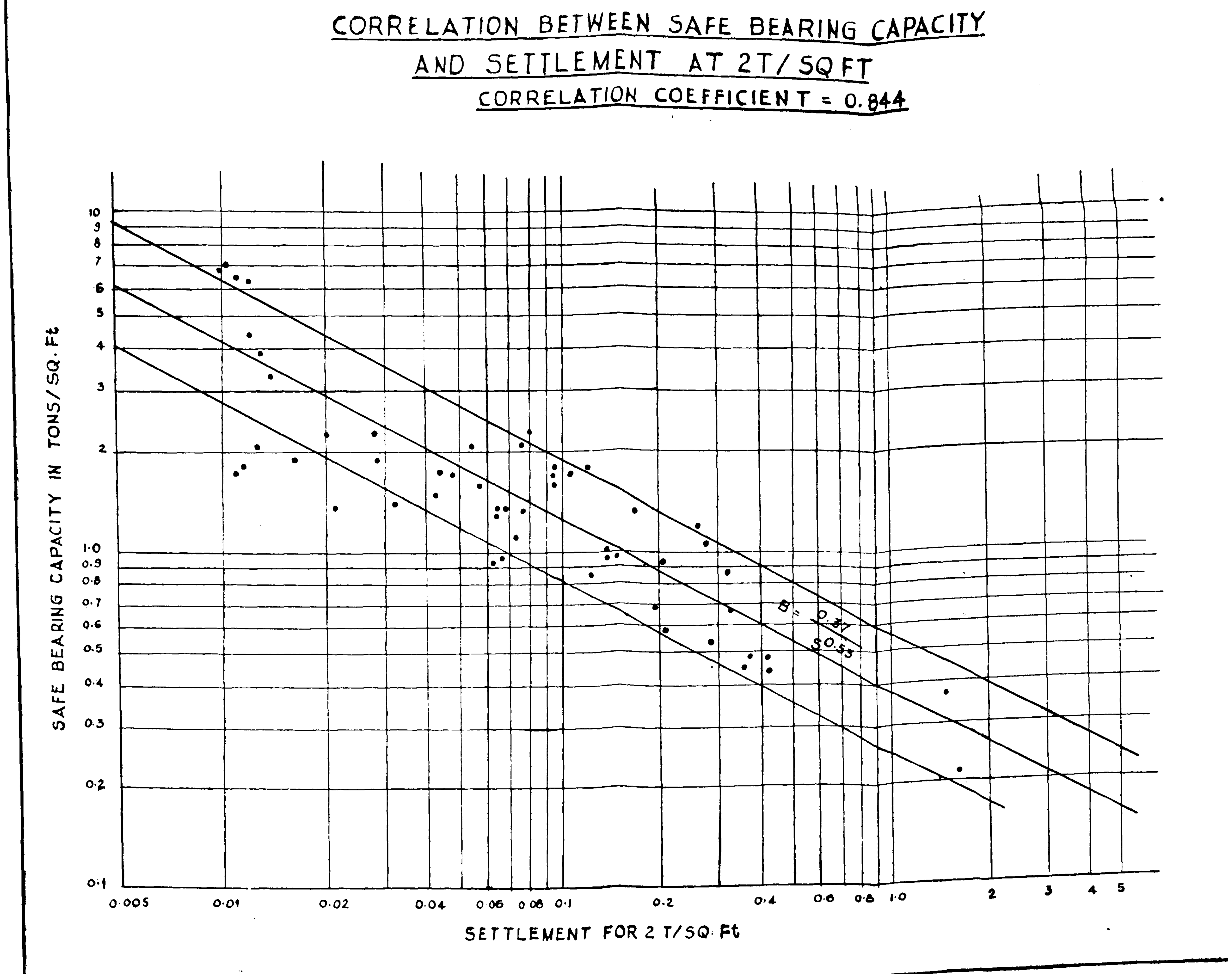
(*c*) Water table.

(*d*) Soil profile.

(*e*) Vibrations.

3.1. *Depth of foundation.*—The stress zones developed by a loaded footing when it is placed at ground level and when located at a depth below ground level are shown in Figure 6. It will be seen that a footing settles into the ground by compressing the soil underneath and pushing aside the surrounding soil which tries to rise to the surface adjacent to the footing. If a surcharge is placed around the footing, the load due to the surcharge resists the upward movement of the soil, and this increases the resistance to penetration by the footing. In effect the bearing capacity is increased. The increase of bearing capacity is given by a factor-r Df Nq, where r is the unit weight of the material. Df is the depth

FIG 8


CORRELATION BETWEEN SAFE BEARING CAPACITY
AND SETTLEMENT AT 2T/SQ FT
CORRELATION COEFFICIENT = 0.844
SAFE BEARING CAPACITY IN TONS/SQ. Ft
SETTLEMENT FOR 2 T/SQ. Ft
B = 0.31 / S0.53
10
9
8
7
6
5
4
3
2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.005
0.01
0.02
0.04
0.06
0.08
0.1
0.2
0.4
0.6
0.8
1.0
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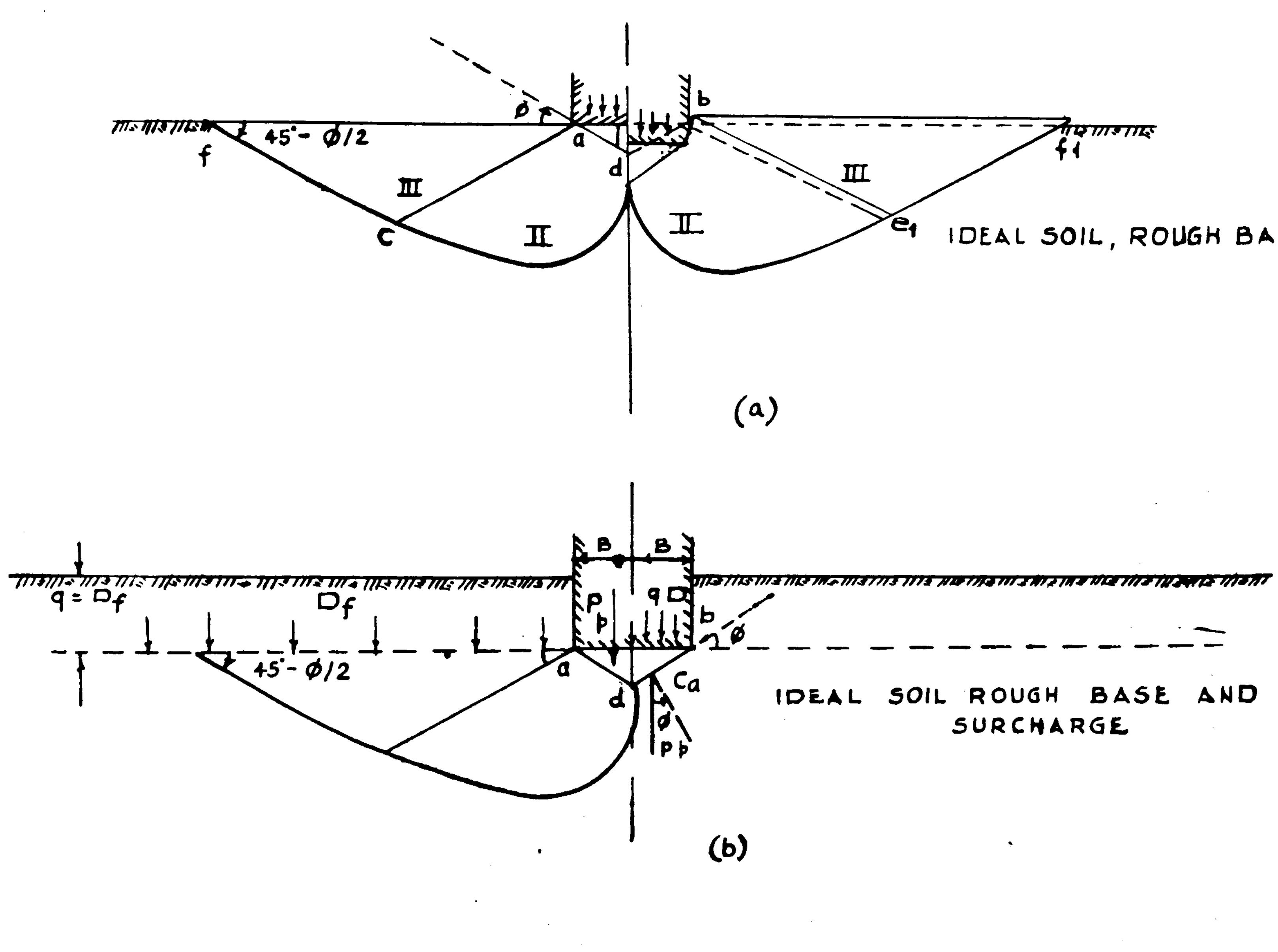
3
4
5

FIG.6



IDEAL SOIL, ROUGH BASE

(a)

IDEAL SOIL ROUGH BASE AND SURCHARGE

(b)

of the foundation below ground level and Nq is a factor which depends upon the type of material. Nq is governed by the angle of friction of the material and varies between 1 and 20. For clays and highly clayey soils with angle of friction $\phi=0$, Nq is equal to 1. For loamy soils with angle of friction between 15 and 25, Nq may be taken as 2 and for sandy materials it may be taken as 5. This clearly indicates that an increase in the depth of foundation definitely increases the bearing capacity even though the type of material met with is the same. This factor can be taken advantage of, in various foundation designs and is the basis of a special foundation design usually known as a "floating foundation". This type of foundation is specially applicable to soils having very poor bearing capacity. The basic idea is that a raft type of foundation is used along basement floor and the raft is laid at such a depth that the unit load on the raft is equal to the weight per square foot of over burden removed before the raft is laid. A foundation of this type is particularly suitable where loose material of low bearing capacity is met with extending to great depths or in case, the foundations have to be laid over deep beds of clay and settlements due to consolidation of clay are to be minimised.

3.2. *Size and shape of loaded area.*—A circular bearing area develops equal resisting pressure at all points on its boundary, while in the case of square or rectangular areas, the stresses at the corners are relatively higher than that at other points on the perimeter. In the case of a strip footing, the effect of corners is relatively negligible as the length is large compared to the width. Due to this stress concentrations at corners, etc., the shape of the loaded area has an effect on the bearing capacity.

Although on initial examination, it may appear that as we are only dealing with loads per unit area, the size of the footing should have no effect on the bearing capacity, still a detailed examination has indicated that the size of the footing also controls the bearing capacity depending on the type of soil stratum under consideration. Theoretical investigations as also practical tests have shown that for highly cohesive soils with angle of friction $\phi=0$, the bearing capacity is not affected by the size of the footing. But in the case of loamy and sandy soils, the bearing capacity increases with the size of the loaded area.

In addition to affecting the bearing capacity, the size of the loaded area also affects the settlement, to which the footing will be subjected at the same intensity of loading. For a given intensity of loading, the larger the width of the footing, the greater is the depth to which the pressure bulb corresponding to a particular fraction of the applied intensity penetrates. Hence a larger mass of soil is stressed and the corresponding changes in volume and consequent settlements are larger. For cohesive soils the settlements are governed by the formula:

$$\frac{S_2}{S_1} = \frac{B_2}{B_1} \quad \cdots \quad \cdots \quad \cdots \quad (6)$$

and for cohesionless soils by the formula:

$$\frac{S_2}{S_1} = \left[\frac{B_2\ (B_1 + 1)}{B_1\ (B_2 + 1)}\right]^2 \quad \cdots \quad (7)$$

where S_1 and S_2 are settlements in the case of loaded areas of widths B_1 and B_2 respectively.

3.3. *Effects of variation in ground water level.*—It is not uncommon to experience considerable variation in the ground water level at a given site. This may occur due to climatic changes or the water table may be lowered due to construction operations, or by pumping from wells for water-supply, etc. In the case of cohesionless soils, the effect of submergence is to reduce the unit weight of the soil and this in turn affects the bearing capacity. Generally, the effect of submergence is to reduce the bearing capacity by half.

The effect of seasonal variations of water table in the case of highly cohesive clayey soils is more complicated than the above. Change of moisture content will affect the cohesive strength and angle of internal friction of this material. Further, increase of moisture may result in

swelling and decrease of moisture in shrinkage. Depending on the type of material, the range of moisture variations and the applied load intensity, movements may be induced on the footing due to corresponding movements in the soil stratum. This phenomenon will also have to be taken into account in considering the effect of the change of moisture content. Hence in such cases a thorough and careful examination of the various aspects is necessary before adopting any safe bearing value for the stratum (6) (7).

3.4. *Effect of underlying weak substrata.*—We have so far been discussing cases where more or less uniform type of soil extends to considerable depths. In many sites it may so happen that such conditions do not exist but that different types of soil strata occur one below the other. If the underlying stratum happens to be a more stable one as compared to the over lying stratum, then a foundation designed for the overlying stratum will be safe and in most cases no radical modifications may be required to take into account the presence of the underlying stratum.

But in the other case, where the underlying stratum is weaker and less stable, then a careful analysis of the stress distribution and intensities of loads transmitted to the underlying weaker stratum will be required to ensure that the weaker stratum is not stressed beyond safe limits.

Various methods are available to compute the stresses induced by different loads at various depths. A simplified procedure which is applicable as a first approximation is discussed in a later section of this paper. In this connection the concept of significant depth is also to be noted. This significant depth is the depth to which application of the load materially alters the state of stress in the soil mass and consequently is the depth within which, the existence of a weak stratum will affect the bearing capacity and settlement. This matter will be discussed in greater detail in a subsequent article.

3.5. *Effect of vibrations.*—In the case of loose cohesionless soils, vibrations transmitted to the foundations will induce a re-arrangement of particles and a consequent settlement. But such rearrangement may increase the bearing capacity. Thus vibrations transmitted to the foundations, especially in the case of loose cohesionless materials, may produce large settlements even though there may be an increase of bearing capacity. In such cases, it may be advantageous to densify the strata by vibrations before the foundations are laid. Equipment have been developed to vibrate even deep layers of loose cohesionless materials (8), (9). Effect of vibrations on bearing capacity in the case of cohesive material is more complex and in case appreciable transmission of vibrations to the foundations is anticipated, then a special study of the problem may have to be undertaken (10).

4. Settlement considerations.

So far, the determination of bearing capacity considering only the shear failure of the soil has been discussed. Even a building with footings that exert the allowable soil pressure will have some settlement. Hence foundations are to be designed so that settlement from any cause is limited to some specified value. Nowadays an analysis of settlement due to soil compression, if undertaken at all, is often regarded as a secondary rather than primary operation and one which is of interest chiefly in clays. As a result there has been a growing tendency to consider that the allowable soil bearing value is related principally to shearing strength and that factors which affect shearing strength alone, alter bearing value in like degree. An unconfined, but highly incompressible soil, however, would fail in shear before appreciable settlement due to compression could occur. But in the case of highly compressible soils which, under moderate loading, would compress significantly, more attention has to be paid to the analysis of settlement even for loads smaller than the allowable soil pressure and especially for differing conditions of footing size, depth and surcharge.

4.1. *Relation between allowable pressure and settlement due to soil compression.*—Soil compressibility is conventionally expressed in terms of the change in void ratio Δe of the soil produced by a given change in loading. The compression index is generally defined as

$$C_c = \frac{\Delta e}{\Delta \log P}$$

where Δe = Small change in voids ratio for a corresponding change in pressure Δ P.

From this definition, the change in voids ratio for a given change of pressure can be expressed

as $$\Delta e = C_c \log\left(1 + \frac{\Delta P}{Pi}\right) \quad .. \quad (8)$$

wherein Pi—initial vertical stress under which an element of soil at given depth has been consolidated prior to the application of boundary loading which creates stress increment Δ P and Δe is the consequent change in voids ratio.

Also we know that the change in thickness of soil elements due to such compression is related to change in voids ratio by the expression

$$\Delta H = H \times \frac{\Delta e}{1 + e_o} \quad .. \quad (9)$$

where H—Initial thickness of the compressible material and e_o—initial void ratio.
combining equations (8) and (9) we get the familiar expression

$$\Delta H = H \times \frac{C_c}{1 + e_o} \times \log\left(1 + \frac{\Delta P}{Pi}\right) ..(10).$$

The equation (10) indicates that the change in thickness of a soil element or layer due to one dimensional vertical compression is a function of the ratio of the stress increment to the initial stress on the element and the proportionality factor is the quantity $\frac{C_c}{1 + e_o}$ a term known as a compression ratio which involves both compressibility and the initial density of the soil. This equation is usually used for calculating the total settlement that will take place in a clay layer due to consolidation produced by any applied load. But this equation may also be used to calculate the change in thickness of a soil layer due to a specific change in stress. It may be rewritten as

$$\Delta P = \left(10^{\frac{\Delta H}{H} \cdot \frac{1 + e_o}{C_c}} - 1\right) Pi$$

$$= \left(10^{\frac{SC}{H}} - 1\right) Pi....(11)$$

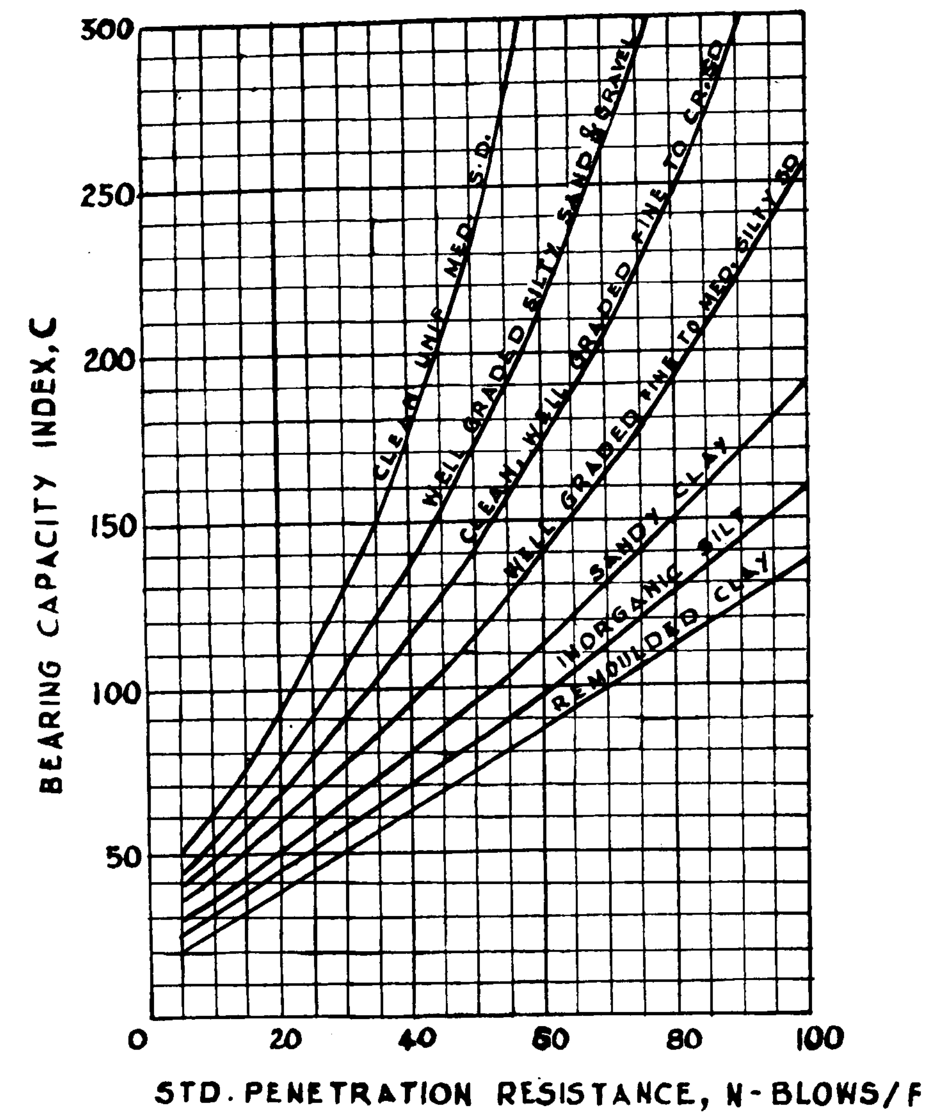
where S = Δ H (Settlement) and $C = \frac{1 + e_o}{C_c}$

It can be shown that the term 'C' which is the reciprocal of the compression ratio, is to some extent an index of the soil bearing capacity and is usually referred to as the 'bearing capacity index.' The bearing capacity index may be calculated by determining Cc and e from consolidation test or directly obtained from Figure 7 which gives a correlation between the bearing capacity index and standard penetration test data. Equations have been developed for using this criterion under various stress distributions normally met with in the field, and to calculate the safe bearing capacity which will produce a settlement that will not exceed any given value (11) The application of this procedure for a practical case is described below.

Practical method.—For any soil strata, first the bearing capacity index 'C' (which is $\frac{1+e_o}{C}$) has to be determined. This may be obtained by conducting a consolidation test in the laboratory on undisturbed soil sample taken from the site and determining the compression index Cc and void ratio e_o.

The value of bearing capacity index may also be obtained by using the chart in Figure 7 . The allowable pressure index may directly be obtained from chart (Figure 8) for the particular value of bearing capacity index, allowable settlement 's' and particular width of footing 'B'. Then the allowable bearing pressure is obtained by multiplying the allowable pressure index by the density of the soil. The sub-soil particulars for use in these computations must be obtained up to the depth of significant stress. The footings designed by this method will be safe against settlement.

FIG·7



BEARING CAPACITY INDEX VALUES

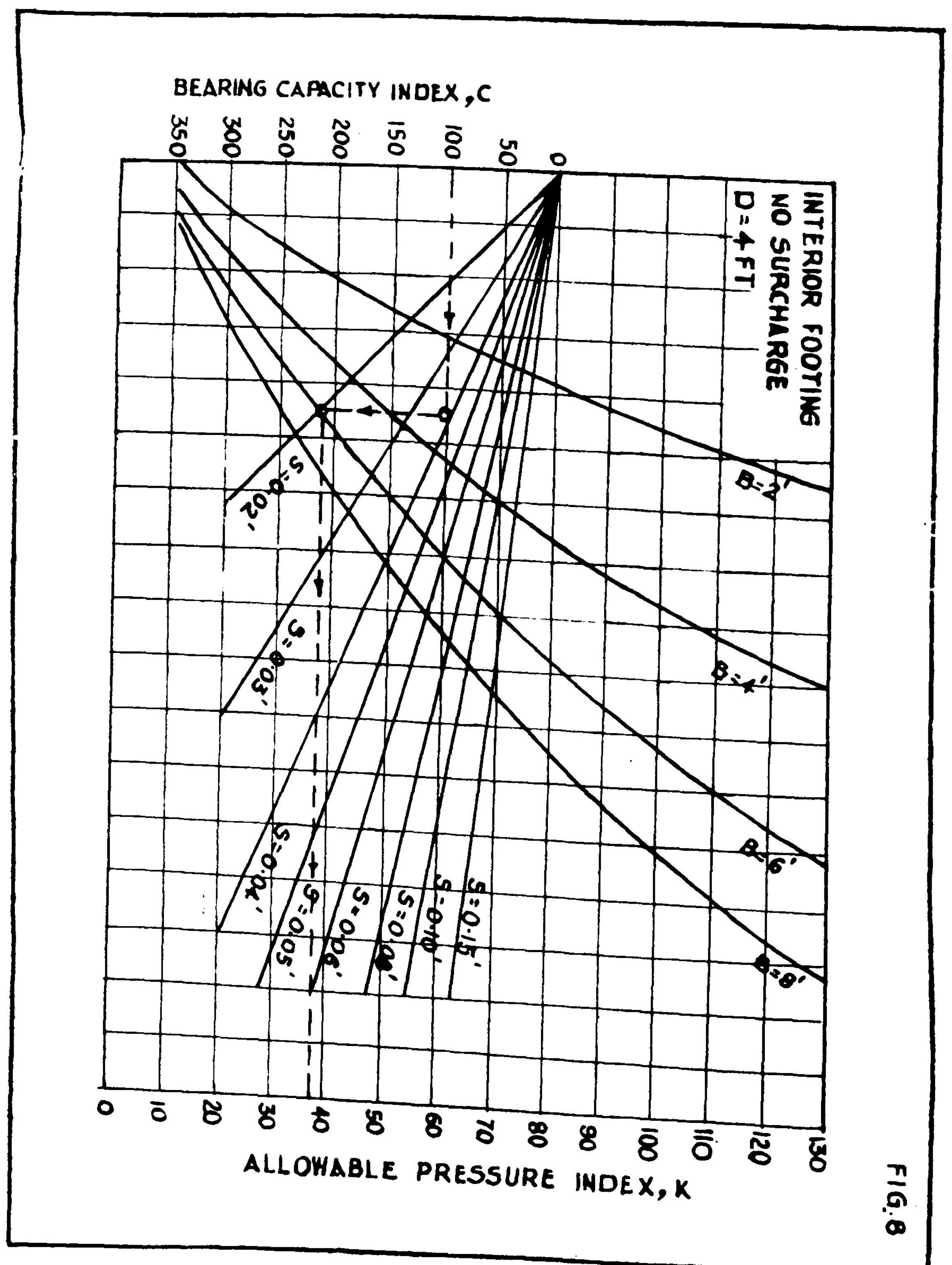


FIG. 8

So far the design of only footings for individual columns, especially square footings have been discussed. When a loading of given intensity is applied to a continuous footing, the stress increment ΔP at a given depth below the footing is greater than what would be the case with an individual footing due to stress overlap. Hence with a given intensity of pressure, the depth of significant stress and thickness of compressible material is greater than for one individual footing. For equal settlement, the intensity of allowable pressure on the continuous footing must therefore be less. There is also evidence that the ultimate bearing capacity of soil beneath a continuous footing is less than that of soil beneath an individual footing. On the basis of experience, it appears that a 25 per cent reduction of allowable pressure values obtained by the above procedures will usually be appropriate for design of continuous footings.

5. Suggested Norms for site examination.

Both the factors, viz., stability against foundation shear failure and settlement due to compression are important in deciding the safe bearing capacity at any particular site.

An adequate exploration of the sub-soil below the foundation level upto the significant depth should be conducted and the properties of the different soils in this depth should be taken into consideration in the foundation design. Practising Engineers should not rest content with examining the soils just at the foundation level, but should examine the soil conditions upto a sufficient level below the foundation.

The use of the safe bearing capacity values found in building codes and hand books, based on a simple visual examination of the site should be limited to very small and simple structures transmitting low loads (Total cost of building Rs. 5,000 or less).

In the case of small buildings (costing between 5,000 and 10,000) at least one trial pit to a depth of a few feet below foundation level should be made and a few samples tested in the laboratory. The bearing capacity may be estimated using the voids ratio method or the simpler equations (equations No. 1 and 3).

In the case of a medium building (in the range 10,000 to 50,000) a number of trial pits may be put in and the required number of undisturbed samples taken and tested in the laboratory to get a fair idea of the bearing capacity. The simplified load test suggested in this paper may also be used with advantage for such cases.

For the more important buildings costing above Rs. 50,000 and upto 2 lakhs of rupees, depending on the site conditions, a few borings should be made upto the significant depth and samples obtained to know the type and extent of soil strata occuring below the foundation level. Sufficient undisturbed samples may be collected and tested. At a number of places standard load bearing test may be conducted and a fair estimate of the bearing capacity obtained.

In the case of big structures costing more than 2 lakhs of rupees adequate soil exploration should be conducted including a sufficient number of borings and load tests in addition to testing undisturbed samples. Such investigations will also provide a basis for a choice between different types of foundation designs that may be adopted to suit the site. Only by adopting a procedure similar to that suggested above, a rational evaluation of the bearing capacity can be made.

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RECOMMENDATIONS FOR ENSURING SAFETY OF HYDRAULIC STRUCTURES

(Planning, Design, Construction and Maintenance)

by

DR. D. V. JOGLEKAR.*

1. The Panshet dam 25 miles upstream of Poona on one of the tributaries of the Mutha River and the Khadakvasla dam 11 miles upstream of Poona on the main Mutha River failed on 12th July 1961 causing vast devastation and untold miseries to the city of Poona. The Government of Maharashtra appointed one man Commission to enquire into the report on (1) on causes of the failure of the Panshet and Khadakvasla dams on the 12th July, 1961 and the circumstances in which such failure occurred; (2) the adequacy of the action by the various authorities before, during and immediately after the disaster to avert it or to mitigate the consequences thereof.

2. Shri Justice V. A. Naik conducted the enquiries. Assistance was given to the Commission by two Assessors, Shri A. C. Mitra, Engineer-in-charge, U.P. and Shri C. L. Handa, Member (Designs and Research), C.W. & P.C. The report was submitted to the Government and has now been published.

3. Assessors and Justice Naik have made certain recommendations to ensure the safety of earth dams. It is most vital to scrupulously follow these recommendations by all the Departmental agencies.

4. In this connection the Commission has recommended a very close association between Designs Organisations and Research Stations in addition to the emphasis on team work between planning, designing and construction organisations.

5. Sometimes it happens that the Designers feel hesitant to approach the Research Stations between (i) the Designs have been prepared on cerain standard procedure, and hence think it unnecessary to refer such problems to research; (ii) They feel that some delay is likely to occur if such problems are referred to research. However, remembering that conditions may differ from project to project, it is always desirable that the designs are checked by proper tests; for instance spillways, high head structures, such as gates, valves, etc. As regards delay in getting the results, so much depends on the timely supply of necessary data for models of hydraulic structures. From the Designer's point of view, the design may be absolutely safe, but he cannot always anticipate the hydraulic behaviour and the world-wide practice now is to get the designs checked by model tests.

6. As a matter of fact the Designs Organisation and the Research Organisation should work as a team. A good Designer may not be a good Hydaulician and vice versa. Personal prestige or prestige of the organisations should not stand in the way of solving intricate problems by hydraulic research. There should always be mutual discussions with an open mind from time to time during experimentation and any dogmatic approach to a problem should be avoided.

7. Some Research Stations insist on terms of reference before accepting a particular problem and then try to stick to these while sending report on their findings. Though it may be desirable to know the points for which solutions are required, it is not always possible to estimate them pro-

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perly before hand. It is often found that during experimentation many other points affecting the design, and not covered by the terms of reference emerge and hence as stated above, mutual discussions during experimentation should be carried out to ensure that the designs are safe under all contingencies. In other words the terms of reference should be flexible and not rigid.

8. There is also another reason why sometimes delay occurs. The administrators and or engineers ask for the salvage value of materials such as small pumps, pipes, plastic tubes, wood materials etc, required for models, before the estimates prepared by the Research Stations are accepted by them. These lead to unnecessary correspondence and important model investigation is likely to be held up sometimes leading to disastrous results. After all the cost of such material is negligible as compared to the intrinsic value of the advice given by the Researchers. The same materials are generally used by the Research Stations for some other model experi ments or for developing the Research Stations i general. Hence such questions should be avoide in future.

9. In the National interest, it is essential tha the Administrators should know various engi neering structures, which are being constructed It may be that due to multifarious duties th administrators may not find time to such project It is, therefore, felt that more efforts should b made by engineers in-charge of Projects to giv wider publicity. They may take the civil officer and other interested to the site of work an explain various points of interest. They may als be taken to the Research Stations where suc problems are under investigation. As a matte of fact there should be a complete coordinatio between the engineers and the administrators an if quarterly meetings are held, they would go long way in ensuring co-operation between th public, civil authorities, engineers and scientist

NEWS ROUND UP.

1. Sasthavinallur Tharuvai Drainage Scheme:—

The Sasthavinallur Tharuvai Drainage Scheme in Sasthavinallur village, Tiruchendur taluk, Tirunelveli district was inaugurated by the Hon'ble Home Minister of Madras, Sri P. Kakkan on 16th February, 1964. On that occasion, the Chief Engineer (Irrigation) welcomed the gathering and gave a brief account on the advantages of the scheme and remarked that the forlorn wishes of the people of this area are being fulfilled that day.

On completion of the scheme, 480 acres of land will be saved from submersion and this in turn will add 48 tons of food grains. The total estimated cost of the scheme is Rs. 65,000.

2. Parakkirampandian Tank:

Restoration of Parakkirampandian tank in Gangaikondan village, Tirunelveli District is the second stage of the Seevalapperi tank scheme. The scheme estimated at a cost of Rs. 7,27,300 was inaugurated by the Home Minister of Madras, Sri P. Kakkan on 16th April, 1964 to the great jubilance of thousands of villagers deriving the benefits of the scheme. Sri K. V. Ekambaram, I.S.E., Chief Engineer for Irrigation, P.W.D., who welcomed the gathering said that this new scheme would benefit an area of 730 acres of dry lands. Three hundred and sixty-five tons of food can be raised from the proposed ayacut.

3. Melakaranthai Tank:

The Melakaranthai tank scheme under Minor Irrigation Scheme which is a new formation of tank across Uppodai near Melakaranthai village in Koilpatti taluk, Tirunelveli district estimated at a cost of Rs. 9,39,400 was inaugurated by the Hon'ble Home Minister of Madras Sri P. Kakkan on 16th April, 1964 and Sri Chellapandian, B.A., B.L., Speaker, Legislative Assembly, Madras was on the chair. On the occasion, Sri K. V. Ekambaram, I.S.E., Chief Engineer (Irrigation), P.W.D., Madras, welcomed the gathering, pointing out that on completion of the scheme an additional food production of 460 tons could be possible.

(1)	(2)	(1)	(2)

A wise old owl lived in an oak
The more he saw ; the less he spoke
The less he spoke ; the more he heard
Why can't we all be like that old bird

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