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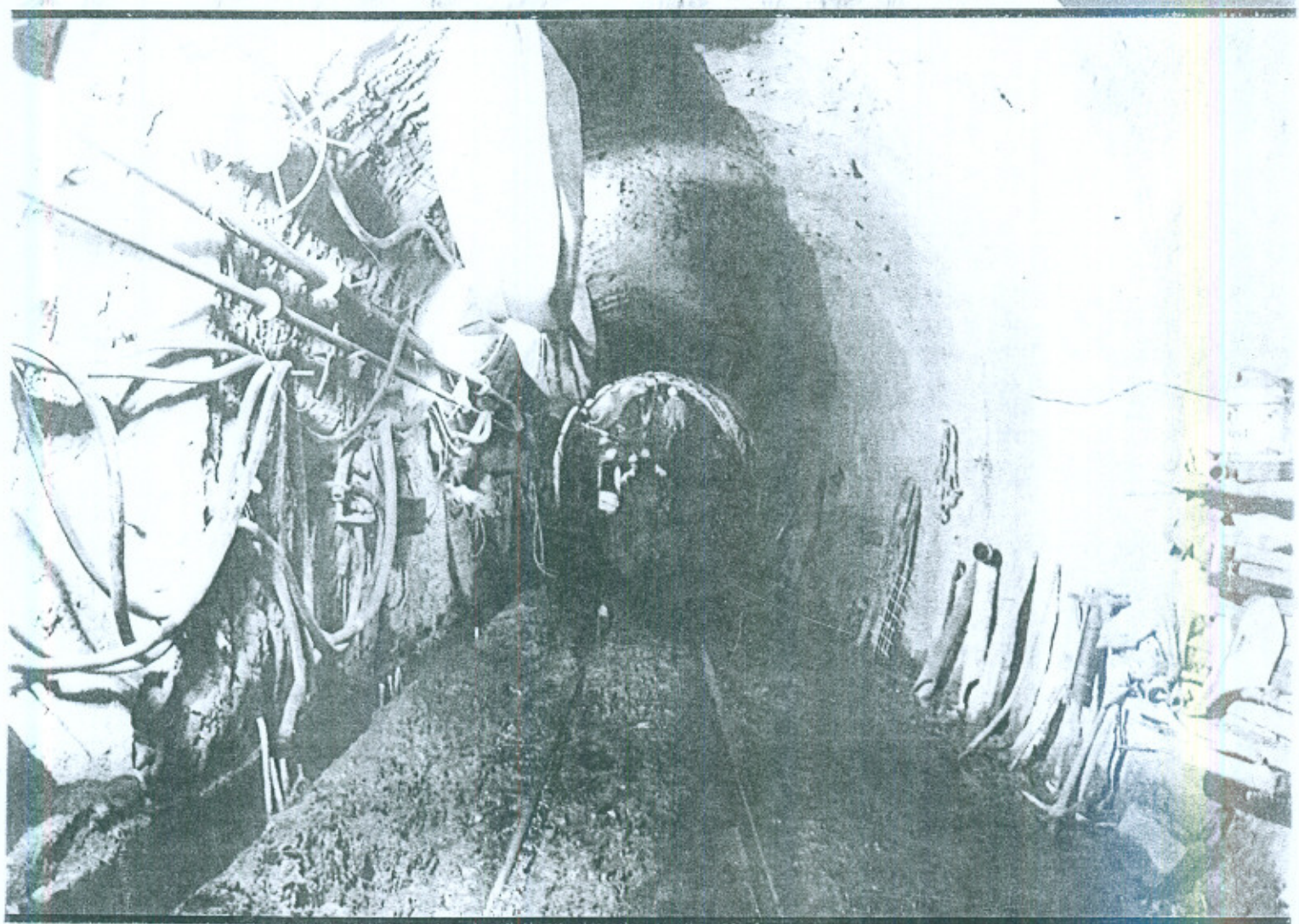

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COVER PHOTO

View of the Tunnel of Pehur High Level Canal

Courtesy : **National Development Consultants**

45th YEAR OF PUBLICATION

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EDITORIAL

KALABAGH DAM IN THE CONTEXT OF WORLD TRADE ORGANIZATION EXPORTS EFFECTIVE 2005

President of Pakistan General Pervaiz Musharraf deserves all the laurels that in his Television and Radio Address to the nation in September 2003, he seized the opportunity to categorically pronounce that the construction of Kalabagh Dam or Basha Dam must start by June 2004 to meet the country's water requirements for the next 50 years. He boldy held out that 'If we fail to take a decision our coming generations will never forgive us'. It is abundantly clear that in the distance future, without Kalabagh Dam the entire irrigation system of the Indus plain would become redundant, and fertile lands would be rendered desolate and barren. In addition, the entire industry would also grind to a halt with costly thermal power not being able to produce goods at competitive rates in the context of challenges to be faced by our exportable products under WTO starting from 2005.

There are no two opinions that already Mangla Dam and Tarbela Dam have so far silted upto the extent that their respective storage capacities have shrunk by 25%. This capacity is fast depleting and the day is not far off when these Dams will cease to store to shore and supply irrigation water to the national irrigation network.

Thus to construct more reservoirs, including Kalabagh Dam, is the dire necessity. It is heartening that the Government has taken in hand the feasibility studies of Basha-Diamer and Akhori Dams on the Indus and construction of several high-head and low-head hydropower projects to supplement the existing electricity production in order to counter the ever increasing thermal power tariff.

Construction of Kalabagh Dam, which is technically and financially viable would in fact be a replacement of the fast depleting storage capacity and consequent reduction of electricity production of both Tarbela Dam and Mangla Dams. Others to follow will be Basha and Akhori Dams.

He pleaded that the politicians with their vested interests must shun their intransigence and reach consensus in the larger national interest and leave behind a good name to be cherished by the posterity which otherwise is doomed to oblivion in the history of mankind.

WELCOME TO NEW MEMBERS

The Executive Council of the Pakistan Engineering Congress approved Membership of the following new members in to the Congress fold. The Engineering News congratulates all of them and welcomes to PEC Fold.

Members admitted on 8-11-2003

1 Engr. Asif Liaqat Bhatti

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PRODUCTION OF THE METAL MATRIX COMPOSITE BY MODIFICATION OF A CONVENTIONAL FOUNDRY

By

*** Prof. Dr. Taqi Zahid Butt * Ahmad Khawaja & *Rafey Jamal**

Abstract

The objective of this study was to asses the feasibility for the production of the MMCs by the modification of the conventional foundry. Aluminum Matrix Composite reinforced with Silicon Carbide particles was prepared by a process in which SiC particles were added into an impeller agitated Aluminum Melt. Aluminum matrix of composition similar to the Alloy 6101 was developed and a SiC particles of size under 100 microns was used as reinforcement.

The Composite sample were cast to Standard Rectangular Tensile Specimen and tested for mechanical properties in tensile testing machine. Vickers's Hardness Testing Machine was used for hardness measurement. The results obtained were then compared with the properties of the Alloy 6101.

It was observed that SiC particles reinforcement appreciably improves hardness and strength of the composite. This study also confirms that the particle reinforced composite can be produced locally by Liquid Metallurgy Route.

Introduction

In the continuing quest for improving performance, which may be specified by various criteria including low weight, more strength and lower cost, currently used materials frequently reach the limit of their usefulness. Thus material scientists and engineers are, always striving to produce either improved traditional materials or completely new materials. Composites are an example of the latter category.

It is a fact that technological development depends on advances in the field of materials. Composite material in this regard is big step in the ever constant endeavor of the optimization of the material properties. The reinforcement of the metals both by particle and fiber can give substantial improvements in both strength and stiffness over unreinforced alloy.

There are number of experimental examples in the literature [1,2] which clearly demonstrate the influence of the reinforcement of matrix metal on the mechanical properties of the MMCs.

Liquid metallurgical technique is most widely used for the production MMCs because of economical benefits [3].The technique is very simple in principle but practically it is very difficult to handle and master. The reason for this higher number of variables involved in the process control. Every variable affects the quality of the product and it is very difficult to find and maintain the optimum values for the process parameters.

EXPERIMENTAL WORK

Raw Material

Alloy 6101 (0.5 % Mg , 0.5 % Si) was selected for matrix not only for its commercial availability but rather more for only Si and Mg as alloying elements. As referred by [4] Mg

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addition decreases the surface energy of aluminum and hence improves the wet ability of Sic. Further benefits of Mg have also been reported like strength and hardness.

Si in minute amount retards the SiC and Al reaction at the interface which causes brittleness and leads to poor mechanical properties [5].

MATERIAL	STATUS
Aluminum	Pure
Magnesium	50 % Al - Mg
Silicon	50% Al- Si
Silicon Carbide	100-150 microns

Table 1 : Shows the status of material used

Facilities

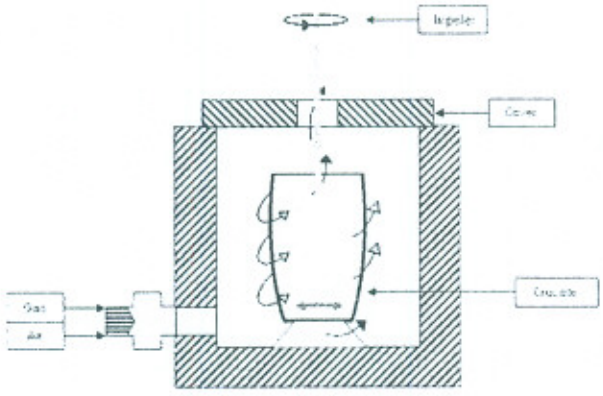

Fig 1 : Shows composite production facility

An adjustable stirring mechanism was designed to ensure uniform distribution of the particles in the melt. It consisted of a stand, motor and the stirrer assembly with a working range of 250 – 300 RPM. Stirrer was inserted in the crucible through the opening in the lid. As non-oxidizing atmosphere was not used thus it required a high degree of temperature control and suitable cover all to ensure minimum oxidation.

Procedure

Pure aluminum was melted in the furnace and maintained at 700°C - 750°C. Required composition was achieved by adding calculated amounts of Si and Mg in the alloy forms. Lower the stirrer assembly till the tip of the impeller is just above the bottom of the crucible. Start agitation from lower RPM and gradually increasing till a smooth vortex is formed. SiC particles (100 - 150 microns) were added in the centre of the vortex. Turn the furnace off but continue stirring for a while to permit maximum adhesion through mechanical entrapment as referred by [6], that the semi solid stirring favors better homogeneity. Melt was then poured into mould to directly cast to the standard tensile specimen.

Precautions

- Ensure that temperature does not increase above the 750°C mark, so that burning of the melt does not take place.
- Owing to the presence of the oxidizing atmosphere suitable coverall is required.

- RPM should be kept minimum to avoid splashing and without compromising quality of the vortex.
- Semi solid stirring should be stopped before reaching the pouring temperature [7-9].
- Whole melting practice should be carried out in the minimum time possible to minimize the interfacial reactions as referred by [10].

RESULTS AND DISCUSSION

Results

Microscopic examination revealed that the desired 10% incorporation of the reinforcement was achieved. Carbide formation at the interface was minimized to negligible effect.

Some Silicon formed as a reaction product will produce Al - Si eutectic at/near the interface, slightly altered the mechanical properties of the composite . Overall, an adequate improvement was recorded.

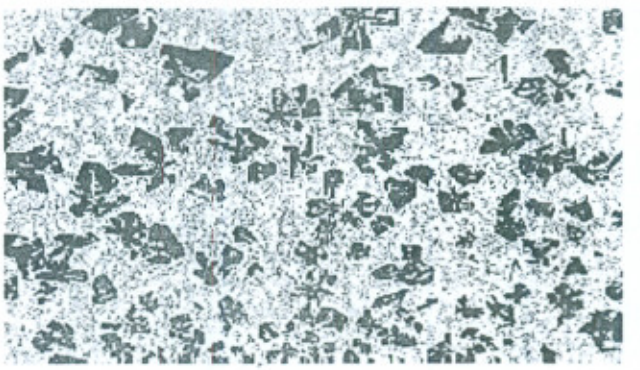

Fig 2 : Microscopic structure showing the incorporation of the reinforcement in the composite material produced (x 400)

Properties	Alloy 6101	Composite
Tensile Strength	94.96 Mpa	109.84 MPa
Yield Strength	71.58 Mpa	98.40 MPa
% Elongation	20 %	4.7 %
Hardness	36.31Hv	53.3 Hv

Table 2 : Comparison of the matrix alloy and the composite produced

Discussion

Consulting the results of MMC produced and its comparison with the matrix alloy, a significant increase in the mechanical properties was observed with-out use of any strain hardening or heat treatment processes.

The hardness of the Aluminum alloy improved adding adequate volume fraction of SiC particles as reinforcement. This should serve to increase the strength of the composite as the hard phase SiC particles must resist the stresses caused by dislocation pile-ups against it. Good coupling at the particle – matrix interface is necessary if the particles are to act as barriers to dislocation motion.

Moreover, it is possible to develop MMCs locally using basic melting / Casting facilities thus paving way for the growth of the composite industry in Pakistan. Some modifications of the

standard procedures used for the unreinforced alloy are required, but they can be easily accommodated in a standard foundry. For example, continuous stirring of the melt to prevent reinforcement from settling is necessary.

The use of finer particles (100 – 150 μm) as reinforcement, should reduce shrinkage porosity, and also serve to augment yield strength and dislocation density of the composite material, as predicted by the micro mechanics approach. In terms of classical fracture mechanics, porosity is treated as pre – existing cracks, they may propagate catastrophically under applied load. Therefore its elimination in competitive manufacturing is highly desirable.

As this process is an extension of the usual foundry process, it inherits some of the problems typical of melting and casting. Problem like blow holes, porosity, cracks, cold shuts and misruns etc. are often encountered while using this technique. These problems are some times more commonly observed as the melt picks up a lot of gas during mechanical stirring. Most of the conventional degassing techniques and salt fluxing cannot be used as these practices may result in rejection of particles from the melt. Consequently, the process has to be very carefully carried out and melt should be carefully degassed to avoid these defects.

CONCLUSION

The following conclusion can be drawn from the above research work:

- Liquid metallurgy technique can be used for the production of Al / SiC MMCs.
- The hardness of the Aluminum matrix can be significantly improved by adding adequate volume fraction of SiC particles as reinforcement.
- Tensile strength improves isotropically appreciably.

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FUTURE MANAGEMENT OF WATER RESOURCES

By

J. C. I. Dooge*

The current situation in relation to water resources, water needs, and key water problems is evaluated. The development over the past few decades of a holistic approach to the management of water resources is reviewed. This new viewpoint involves a combination of appropriate economics, appropriate ecological management, and adoption of a participatory approach, in addition to the appropriate technology. An outline is presented of the progress in international dialogue and cooperation from the Dublin International conference of January 1992 on Water and the Environment to the World Water Vision, presented to the Second World Water Forum at the Hague in March 2000, and the more recent discussions which formed the background for the Third World Water Forum held in Kyoto in March 2003.

GLOBAL WATER RESOURCES

Life began and evolved in the oceans and consequently water and its properties are an intrinsic part of our physical and biological make-up. Social settlements first arose close to sources of water and subsequently water has always been an important element in our social structures. Today water remains a vital element for health, development and the environment involving a variety of experts – scientists, engineers, economists sociologists as well as decision makers at all levels.

Professor Federico Mayor, when Director-General of UNESCO, wrote of the global nature of the responsibility of experts in the latter fields as follows :

> In many areas – the environment, health, energy, telecommunications, education, science policy and the protection of intellectual property – it no longer makes sense to construe problems purely in national terms. In a world that is becoming daily more interdependent, policy-making assumes an increasingly global dimension.

It is for reason that the following discussion emphasises global water problems as well as national and local problems.

The key role of the water environment in relation to present global environment problems was well summarized by Ayibotele and Falkenmark in the chapter on freshwater resources of the Agenda of Science for Environment and Development (ASCEND), produced by the International Council of Scientific Unions as an input to the Rio Conference on Environment and Development :

(a) Water is a unifying agent of the natural ecosystems with functions similar to the blood and the lymph of the human body.

(b) Water is consumed in bio-mass production which is therefore limited by local water availability.

(c) Water circulation is an important element of the global cycle and in this sense is intimately related to the climate.

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* Professor James Dooge is a renowned engineering hydrologist and has written a great number of learned papers on theoretical hydrology for which he has received many international honours. He was Professor of Civil Engineering at University College Dublin from 1970 – 1984, and is presently a Research Consultant in the Center for Water Resources Research, University College Dublin.

(d) Water is fundamental resource on which depend the life support systems and which has to be equitably shared between all those living in a particular river basin.

(e) Water is a crucial link in the causality chain producing bio-diversity disturbances.

Table 1. Water Needs by Use

Type of Use	Water use (km^3 / year)		
	1900	1950	2000
Agriculture	525	1124	2535
Industry	38	182	748
Municipal	16	53	386
Reservoir loss	0.3	6.5	211
Total	579	1365	3940

The past few decades have seen a tendency for the gradual replacement of a purely engineering approach to water management by a wider approach to the problem involving people with diverse backgrounds. The past few years have seen a more systematic focusing of this tendency through specific procedures.

The demand far water is growing at an increasing rate due to both the growth in population and the growth in development. Table 1 shows water use in 1900 and 1950 and the projected use in the year 2000 as estimated by Shiklomanov. [3] This shows the contrast of a 189% increase in the second half of the 20th century compared with 136% in the first half. While agriculture remains by far the largest consumer of available water, the rate of increase is substantially higher in industrial consumption due to development and in municipal consumption due to urbanization and in higher evaporation losses from reservoirs due to the construction of large scale hydro projects.

Table 2 shows the estimated growth of water needs in each continent (except Antarctica) from 1980 to 2000 indicating the variation between continents and that massive population of Asia results in that continent accounting for almost 60% of the global water demand.

Table 2. Water Needs by Continent

Continent	Water use (km^3 / year)		
	1980	2000	Increase
Africa	168	230	37%
Asia	1784	2245	26%
Australia / Oceania	29	33	14%
Europe	445	534	20%
North America	663	718	8%
South America	111	180	62%
All Countries	3200	3940	23%

Countries with less than 1000 m^3 per person per year have been characterized as being countries of extremely low water availability (EL) and those between 1100 and 2000 m^3 per person per year as very low availability (VL). Similarly countries at the top end of the scale with more than 50 000 m^3 per person per year are classes as very high availability (VH) and countries with between 20 100 and 50 000 as high availability (H).

The wide variation between the water availability in individual countries, covering more than three orders of magnitude, is indicated in Table 3 which shows examples from the two lowest and two highest categories as defined above.[3]

Table 3. Variation in Water Availability

Country	Population (1994) millions	Availability (2000) m^3/person/year	Category
Jordan	5.2	120	EL
Tunisia	8.7	310	EL
Pakistan	137	490	EL
Poland	38.3	1200	VL
India	919	1380	VL
China	1209	1860	VL
Sweden	8.74	20000	H
Russia	148	29000	H
Brazil	159	40100	H
New Zealand	3.5	83000	VH
Canada	29	117000	VH
Guyana	0.8	291000	VH
World Average	5629	6800	—

TRANSCENDING TRADITIONAL APPROACHES

In the case of each of the main water uses listed on Table 1, traditional methods of water management have arisen in different climates and cultures. In the past few decades, new methods of management have emerged based on certain principles that are global in scope but can be adapted to local conditions. The input concerning water problems to the Rio Conference on Environment and Development (UNCED) was the concern of the International Conference on Water and the Environment (ICWE) held at Dublin in January 1992.[4] The latter conference collated a large number of input from UN agencies, governments and non-governmental organizations and produced from them the Dublin Statement on Water and Sustainable Development based on four guiding principles. The first of these principles stated :

> Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. Effective management of water resources a holistic approach linking social and economic development with protection of natural ecosystems.

This paper is, in effect, a discussion of these four guiding principles and their gradual adoption. The transition from traditional to integrated management is illustrated below for two cases : (a) rural water supply in developing countries which directly affects human life and health and (b) large multipurpose hydro projects.

The water-related diseases with the greatest global impact are listed on Table 4 together with estimates of the number of cases per year. Viewed on a world basis, the huge incidence of water-related disease is as much, or even more, an effect of deficiency in quantity than a defect in quality.

Table 4. Water-related Diseases

Disease	Case of per year
Trachoma	500 million
Elephantiasis	250 million
Schistosomiasis	200 million
Malaria	160 million
Gastro-enteritis	100 million
Onchpceciasis	30 million

The traditional courses in sanitary engineering and in public health medicine were based on the requirements of improving the urban sanitation of developed economies in temperate climates. In most cases water-related diseases were grouped according to the causative agent, i.e. emphasis was laid on whether the disease was caused by a bacterium or a virus or protozoa etc. The diseases studied were classical water-related diseases such as typhoid and cholera, and more recently infective hepatitis, which do not figure in the listing on table 4 of the major incidence of water-related diseases on a global basis. It is no surprise therefore to find that engineers trained in this traditional way in developed countries were only moderately successful in tackling the problems of water supply and sanitation in developing countries.

A key step in changing this situation was the development by Bradley of a classification of water-related diseases based not on the causative agent but on the manner of infection. The four basis categories identified by him were :

(a) Water-borne diseases in which the water acts as a passive agent for the pathogenic organism which is the infective agent (e.g. typhoid and cholera).

(b) Water-washed diseases in which infections decrease when more water is available for domestic washing and personal hygiene (e. g. diarrhoeal diseases such as bacillary dysentery and diseases affecting the skin and eyes such as trachoma and scabies).

(c) Water-based diseases in which a necessary part of the life cycle of the infecting agent takes place in an aquatic animals (e. g. schistosomiasis and guinea worm).

(d) Water-related diseases in which infections are spread by insects that breed in water or bite near water (e. g. malaria, sleeping sickness and yellow fever).

This reclassification had two great advantages. First, by linking the prevalent disease to the manner of infection it suggested the optimum engineering approach (improved quality or greater quantity or protective measures or piping from source to point of use) as shown on Table 5. Secondly, it provided a common terminology for all those who must co-operate together in an interdisciplinary attack on the complex and immense problem of improving water supplies in developing countries.

Table 5. Water-related Diseases

Category	Example	Relevant Improvement
1. Water-borne		
(a) Classical	Typhoid, Cholera	Sterilisation
(b) Non-Classical	Infective Hepatitis	Treatment
2. Water-washed		
(a) Skin and Eyes	Scabies, Trachoma	Greater quantity
(b) Diarrhoea	Bacillary, Dysentery	Greater quantity
3. Water-based		
(a) Penetrating skin	Schistosomiasis	User protection
(b) Ingested	Guinea worm	Source protection
4. Insect-vectors		
(a) Bite near water	Sleeping sickness	Piping from source
(b) Breed near water	Yellow fever	Piping to user

Trachoma, the leading cause of curable blindness, affects 500 million people every year and this severe impact could be reduced by 60% by increasing the water quantity readily available in the affected localities without any improvement in quantity. In the case of schistosomiasis, which affects over 200 million, the reduction due to the availability of an adequate quantity of water could reduce the incidence by 80%. In the case of gastro-enteritis, with an incidence of between 100 and 500 million case per year (depending on definition), the incidence could be reduced by 50% with an improvement in quantity alone.

In the Past, a narrow approach to projects in water engineering has led to unexpected secondary impacts on the health of the local population. A classical case is the investment in extended areas of irrigated land which results in providing in the irrigation canals an optimum environment for the snail that is an intermediate host for schistosomiasis. While such major disasters have been avoided in recent years, there is still a substantial distance to go in order to achieve a holistic approach in this important area of water management.

In the second example, i.e. of large-scale multi-purpose hydro projects, there has been a gradual move towards the involvement of non-engineering disciplines at the design stage[7]. Prior to 1950, the design team in most case was essentially engineering in character with some post-design but pre-decision input by specialized economists. Between 1950 and 1970, such economists were gradually integrated into the design teams and thus able to provide valuable inputs at the formative stage. During the 1970s, environment experts made post-design inputs before political decisions were made on the proposals put forward by the design teams containing both engineers and economists. In the following decade, environmental experts were in turn integrated into the design team. In the 1990s, the people affected by the proposed project were in a number of case involved in the design process from an early stage and in addition non-governmental organizations have become increasingly involved in the debate about ensuing policy decisions. The future need is for the extension of this integrative process to schemes of all types and to management as well as design.

APPROPRIATE ECONOMICS

The old attitude to water as being a free good has long been abandoned by economists but persists in the approach of many people to water problems. Another of the four guiding principles adopted by the Dublin Conference deals with this specific point when it emphasises :

Water has an economic value in all its competing uses and should be recognized as an economic good. Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price.

The unregulated operation of free market forces in the area of water supply has disadvantaged both the urban and the rural poor to an unacceptable degree. Bhatia and Falkenmark[8] reported to the Dublin Conference that in Lima, the cost of water from private vendors was a hundred times the cost of water from public supplies, resulting in those dependent on private vendors having to spend 20% of their income on water even though their consumption was much lower than that of those serviced by public supplies. The health and environmental costs of such a situation must for exceed the direct costs involved. A similar situation exists in many rural areas in the developing world where the daily consumption of water per head depends critically on the degree of availability of water, as is indicated in some classical surveys in Africa in the 1960s summarized in Table 6 due to Ann White.[9]

The minimum figure for unpiped rural supplies is dangerously close to the physiological minimum for the maintenance of life estimated as between 1 and 3 litres of water per day. The effect of such a restricted intake of water must exact a huge toll in energy and capacity to work it appears that the improvement in health is substantial as water use increases to a daily per capita consumption of about 30 litres, is moderate up to a consumption of 100 litres per day (which is about the upper limit for a single tap) and is still detectable up to a consumption per head of 300 litres per head per day.

Table 6. Domestic Consumption of water

Type of Supply	Daily consumption (litres)	
	Minimum	Maximum
Unpiped rural	2	25
Standpipe	10	50
Single tap in house	15	90
Multiple taps	30	300

The Declaration of the Business Council for Sustainable Development which was the official input from multinational business leaders to the Rio Conference[10] emphasised :

Open and competitive markets, both within and between nations, foster innovation and efficiency and provide opportunities for all to improve their living conditions. But such markets must give the right signals ; the prices of goods and services must increasingly recognize and reflect the environmental costs of their production, use, recycling and disposal.

In a UNESCO publication prepared for the Rio conference, the noted economists Jan Tinbergen and Rocfie Hueting[11] wrote :

The market works well but not all factors contributing to human welfare are captured by it. Consequently, market prices and economic indicators based on them, such as national income and cost-benefit analyses, send misleading signals to society and therefore must be corrected. The factor for which correction is most urgently needed is the environment.

The roots of such an approach were clearly set forth 150 years ago by John Stuart Mill in his Principles of Political Economy where he writes of the relationship between private rights and public policy as follows : [12]

> The earth itself, its forests and waters above and below the surface, . . . are the inheritance of the human race. What rights and under what conditions, a person shall be allowed to exercise over every portion of this common inheritance cannot be left undecided. No function of government is less optional than the regulation of these things, or more completely involved in the idea of a civilized society.

Unfortunately, in the intervening years many administrations of various types have treated this principle as requiring lip service only.

It is vital to choose the appropriate economic instruments for each local situation in order to achieve real efficiency in development. Economic instruments cannot achieve everything and if wrongly chosen can be counter-productive. In this connection, both theory and experience indicate that properly designed incentives are more effective than regulatory measures. There is growing acceptance that the Polluter Pays Principle,[13] accepted by the European Union in 1991 for urban waste-water,[14] can be effectively implemented by fiscal measures.[15] Opinion surveys indicate that people are prepared in principle to pay for environmental services on a basis of use but need further education and encouragement to accept it locally in practice.

There is also a need to allow for cultural differences in applying a free market approach to water management. Following the Dublin Conference, concern was expressed in a number of Muslim countries concerning a possible conflict between the Dublin Conference's characterization of water as an economic good and the view of some Moslems that water cannot be bought or sold since it is a free gift of God. This question was discussed in depth at a workshop on 'Water Managements in the Islamic World' held at Amman in December 1998. The Proceedings contain a chapter on 'Islamic Water Management and the Dublin Statement',[16] and another chapter on 'Water Rights and Water Trade: an Islamic perspective'.[17] The former concludes that Islamic thought agrees with all four principles of the Dublin statement. The latter chapter discusses the dissociation between the concepts of God's fundamental ownership and of humanity's 'managerial' ownership and also the subdivision of various water resources by Muslim scholars into private goods, restricted public goods, and public goods.

The difficulty created by the original reaction could have been avoided if the Dublin Conference had spoken of 'the provision of water as an economic good' or 'the use of water as an economic good', rather than the blunt characterization of the water itself as an economic good.

APPROPRITE ECOLOGY

The variety of ecological concerns that need to be catered for in the new approach are well covered in the six verses of a poem composed by Kenneth Boulding as background to a conference discussion in 1968 in relation to irrigation and water development.[18] This section of his 'Ballad of Ecological Awareness' opens as follows with a comment on the neglected economic factors in the classical cost-benefit analysis of a large dam project :

> The cost of building dams is always underestimated There's erosion of the delta that the river has created There's fertile soil below the dam that's likely to be looted And the tangled mat of forest that has got to be uprooted.

The second verse treats of the social consequences of the creation of the new large reservoir.

There's the breaking up of cultures with old haunts and habits lost, There's the education program that just doesn't come across. And the wasted fruits of progress that are seldom much enjoyed by expelled subsistence farmers who are urban unemployed.

The third and fourth verses treat of the subsequent history of the reservoir, the catchments and the river downstream of the dam.

There's disappointing yield of fish beyond the first explosion; There's silting up and drawing down and watershed erosion. Above the dam the water's lost by sheer evaporation; Below, the river scours and suffers dangerous alteration.

For engineers, however good, are likely to be guilty of quietly forgetting that a river can be silty While the irrigating people too are frequently forgetting that water poured upon the land is likely to be wetting.

Boulding next refers to the secondary effects with implications for health and food production.

Then the water in the lake and what the lake releases is crawling with infected snails and water-borne diseases. There's a hideous locust breeding ground when water level's low And a million ecological facts we really do not know.

He ends by emphasizing the defects of classical cost-benefit analysis which ignores indirect costs and indirect benefit :

There's benefits, of course, which may be countable, but which have a tendency to fall into the pockets of the rich. While the costs are apt to fall upon the shoulders of the poor. So cost-benefit analysis is nearly always sure to justify the building of a solid concrete fact while the ecological truth is felt behind in the abstract.

Unfortunately, the newer tools of environmental economics such as cost-effectiveness analysis or resource accounting resemble classical cost-benefit analysis in containing dangerous elements of subjectivity that are often overlooked. The warnings of Kenneth Boulding are still relevant today.

In the second half of the 20th century, there was considerable advance in the study of ecosystems. In this development, the classical reductionist approach which concentrated on the detailed analysis of individual components of a natural habitat was supplemented by a concentration on the interaction and feedbacks between components. This involved an analysis based on simple conceptual models attempting to reproduce the essential operations involved. In ecosystems the chief inputs are light, heat, moisture and nutrients. These primary inputs are transformed by the living system which develops a hierarchal chain. The biological communities that develop under quasistationary conditions can be quite different in rivers and in lakes and between rivers of differing depth. These ecosystems in rivers and in lakes are naturally affected both by the seasonal and by the diurnal cycles.

Apart from the large amount of research by individuals and by institutions, there has also been international co-operation on the question of river ecosystems. UNESCO in 1998 established a project on ecotones (i. e. transition areas between ecosystems of different types) under the joint auspices of two of their programmes ; the Man and the Biosphere Programme (MAB) and the International Hydrological Programme (IHP). In January 1992 the International Conference on Water and the Environment was explicit in regard to the need to protect aquatic ecosystems. The Dublin Statement produced by this Conference[4] clearly outlined its viewpoint on the protection of aquatic ecosystems in the words :

> Water is a vital part of the environment and a home for many forms of life on which the well-being of humans ultimately depends. Disruption of flows has reduced the productivity of many such ecosystems, devastated fisheries, agriculture and grazing, and marginalized the rural communities which rely on these.

In 1996 the International Hydrological Programme (IHP) of UNESCO included a new programme on Ecohydrology as part of it's fifth phase (1996 – 2001) which included projects on the interactions between river systems, flood plains and wetlands and a comprehensive assessment of ecological processes on the surface.

NEED FOR INTEGRATED MANAGEMENT

Besides the appropriate economics and the appropriate ecology discussed above, there is need for what might be termed the appropriate sociology. The holistic approach spoken of must go beyond interdisciplinary research in science and inter-professional co-operation in design and administration to a wider and closer involvement in the management of the successive phases of planning execution and maintenance of future works on the part of all those concerned and those affected by the project. Again the Dublin Conference on Water and Sustainable Development is specific on this point in another of its guiding principles which states :

> Water development and management should be based on a participatory approach involving users, planners and policy makers at all levels. The participatory approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

This principle is relevant both to expansion of the water industry and waste-water infrastructure in developed countries and to the provision of basic sanitary services in developing countries.

The fourth of the Dublin principles is also concerned with participation but in particulary concerned with the role of women. It states :

> Women play a central role in the provision, management and safeguarding of water. This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resource programmes including decision-making and implementation in ways defined by them.

Acceptance of the participatory principle may be easy enough but its implementation is difficult. Moving from the highly centralised model of the past to a new model based almost entirely on local decision-making would not necessarily be an improvement. Over twenty years ago, a multi-disciplinary team – consisting of water experts in environmental engineering community health, economics, social anthropology, administration, and management – studied the results of schemes of rural water supply in Lesotho and recommended as a guide a scheme of controlled self-help shown in outline on Table 7. This scheme[19] was produced 14 years before the Dublin Conference but is completely consistent with the guiding principle quoted above.

Table 7. Controlled Self-help

Activity	Central authority	District office	Local community
Establish	Project selection criteria		
Plan	Gather information Allocate resources to districts	Select villages Invite applications	Preliminary organisation Respond to invitation
Fund	Disburse grants Distribute donor funds	Collect local contributions Prepare project documents	Raise funds and labour on agreed basis
Implement	Technical advice Central purchasing	Technical supervision	Contribute labour
Maintain	Provide funds	Employ staff	Voluntary labour or services

To obtain the maximum possible benefit from investment in water projects, it is necessary to consider at the planning stage the whole anticipated life history of the project and to ensure the availability of complementary inputs following the completion of the basic project. It was earlier noted that the greatest demand use for water is agriculture and that the water demand is greatest in the continent of Asia. Accordingly, it is interesting to consider the estimates made some 25 years ago by the Food and Agricultural Organisation (FAO) of the UN of the effect of complementary inputs on rice yields in various countries in Asia shown in Table 8. [20]

Table 8 clearly shows the potential role of complementary inputs in promoting self-sufficiency in food and in moderating the demand for water in agriculture.

The role of complementary benefits and stages of benefit can be clearly identified in the case of a water supply scheme for a village in a developing country as shown in Table 9. [21] Community participation in planning and operation, competent design and provision for adequate maintenance are essential for maximising the immediate potential benefits of improved health for all and the saving of time and energy for the women and children previously responsible for water carrying. To achieve these potential benefits in full, there must be a new pattern of water use and new habits of hygiene as well as the avoidance of secondary hazards.

Table 8. Complementary Inputs

Water control	Fertilizer use	Additional inputs	Yield t/ha
Nil	Nil	Nil	1.3
Elimination of flood flows	Nil	Nil	1.5
Elimination of drought flows	Low	Nil	1.7-2.7
Irrigation and drainage	Low to Medium	Nil	2.7-3.0
Sophisticated management	High	Improved pest control	4.9
Sophisticated management	High	Diversification Mechanisation	5.9

The release of labour previously devoted to water carrying allows families to escape the limitations of subsistence farming and achieve improvement and innovation in cropping and in animal husbandry. For this to be effective requires complementary inputs of adequate services for agricultural advice, training, marketing, and credit. If this stage of development is successful, it is possible to aim at higher incomes and increased leisure through an integrated rural development programme. Throughout all of these stages there must be an appropriate division of activity and responsibility between the local community, the district office, and the regional or central authority as indicated in Table 7.

Table 9. Complementary Benefits

Immediate	Stage I	Stage II	Stage III
Improvement in quality Quantity Availability Reliability	Save time Save energy Improve health	Labour release Crop innovation Crop improvement Innovation and Improvement in animal husbandry	Higher income Improved health Increased leisure

In a number of developed countries, the principles exemplified above for developing countries have been advocated and partly applied with due regard for the nature of the local economy. In France, a structure of regional and local decision making in regard to water and waste-water has been in operation for a number of years and has been proposed as a model in a number of other European countries.[22] Howe[23] has commented in relation to the United States

> Little new evidence is needed to show that many of the past World War II water development projects in the United States have not been economically nor socially justified.

And goes on to give a number of examples and to argue for an appropriate consideration of efficiency trade-offs. Bredehoeft[24] surveyed the situation in the western United States and stressed that water management is a process of continuous planning. He distinguished the role of three different groups (users, suppliers, regulators) operating at three different levels (federal, state, local). In the category of regulators he distinguished between the roles of capital investor, direct regulator, and the courts. He discussed the shift among the powers of the different groups due to changes over time of factors such as increased concern with water quality or increase of allocation and consumption of water resources towards saturation.

The principles of integrated water resources planning and management as discussed must be implemented by appropriate technology. This will vary from country to country depending on a number of circumstances (climate, stage of development, social structures, etc.) and in any one country will change over time. Technology transfer without thought on these factors is a highly inefficient use of resources. The highest level of rice production is in Japan as reflected in the last line of Table 8. Study of the history of agricultural development in Japan since the beginning of the 20th century reveals that the emphasis was first placed on applications of science and technology in areas other than labour-saving technology. It was by improvement of strains of rice and moderate use of fertiliser that the initial progress was achieved which enabled the later sophisticated production techniques to be applied without social disruption in an improved economy.

RECENT DIALOGUE AND CO-OPERATION

In the years following the first world-wide Water Conference at Mar del Plata in March 1977, there was little cohesive follow-up to the Plan of Action adopted at that Conference. The report of the World Commission on Environment and Development (the Brundtland Commission) in its 1987 report on "Our Common Future" put the concept of sustainable development on the international agenda but made very little reference to the problems of water resources. However, in the case of the Dublin Conference of January 1992, the four principles emphasised in the Conference Statement (holistic approach, economic value of water, participatory approach, involvement of women) have loomed large in subsequent discussions of water problems and their solution. A number of examples are given below of the adoption of these principles as a basis for further discussion and for action.

The Task Force on "Environment – Water" of the European Commission (1996 – 1998), had the threefold mandate :

(a) define water-research priorities in strict consultation with various socio-economic factors concerned.

(b) reinforce the co-ordination between relevant European, national and private research activities.

(c) stimulate an environment favourable to innovation in this sector.

This directly reflected two of the four Dublin principles, namely a holistic viewpoint based on a participatory approach. A central feature of the Task Force approach was external consultation on a broad basis with a cross section of the various stakholders (researchers, water and waste-water utilities, technology and service providers, regulatory bodies, city and land-use planners, etc.) This process resulted in a large list of suggested research priorities which were then organised into 41 research clusters which were grouped under five research areas. The draft action Plan was then discussed at a Validation Workshop attended by over 100 delegates from government departments and agencies, research centers, industry and other organisations. The first of the five research areas was integrated water management. Another was concerned with socio-economic research. This preparatory process played a key role in the formulation of the Fifth Framework Programme for Research and Technological Development (1998 – 2002).

In the case of the World Commission on Dams (1998 – 2000),[28] the 12 member council implemented the participatory principle by establishing a 68 member Stakeholder Forum to act as a sounding board together with a broadly based advisory group, and also by undertaking 17 thematic reviews which were conducted in a participatory manner on such topics as social issues, environmental issues, economic and financial issues, options assessment, institutional processes. In Chapter 9 of its report entitled "Dams and Development : a new Framework for Decision-making",[28] the Commission proposed a set of guide-lines based on a framework of five key stages and decision points. They end the report by expressing the hope that they have been successful in shifting the center of gravity of the dam debate to one focused on options assessment and participatory decision making.

The same basic emphasis on wide participation runs through the World Water Council report entitled "World Water Vision",[29] also prepared in the period 1998 – 2000. This is epitomized by the sub-title of the report : "Making Water Everybody's Business". This report was the result of the recommendation at the First World Water Forum held in Marrakech in 1997 calling for the preparation of a shared vision on The Long Term Vision for Water, Life and Environment in the 21st Century.[29] This initiative was supported strongly by the Global Water Partnership also founded in 1997 to found and support initiatives on global water problems. The

Global Water Partnership (GWP) strongly supported the Vision exercise through regional committees that coordinated the regional vision consultations.

The headline to the opening page of the executive summary of the report on the World Water Vision, stresses that the present water crises "is a crises of managing water so badly that billions of people – and the environment – suffer badly". A few pages later the executive summary characterizes as the most vital needs in future water management the following :

(a) pricing of water services at full cost.

(b) service-oriented management.

(c) empowering communities, women and men.

These key elements – reflections of the Dublin principles – are expanded on in the executive summary and discussed in still greater detail in the body of the 65-page report.

The World Water Vision discussed above was a key input to the Second World Water Forum and the Ministerial Conference held in the Hague in March 2002. This meeting had a strong commitment to openness and attracted almost 6000 participants – water specialists, concerned citizens, politicians, and representatives of diverse organizations. Six hundred delegates, including 120 ministers, attended the Ministerial Conference. The key issues identified by the Forum participants for consideration by the Ministerial Conference were

(a) the treatment of water resources as a common property and not as either a government monopoly or private monopoly

(b) charging the full cost price for water services

(c) rights of access to water and representation in water management bodies

(d) rights of active participation in the planning of water projects and management of water resources.

The main lines of discussion at the World Water Forum have been reported in a number of publications.[10, 12]

In October 2000, an international symposium on the question 'Can Science and Technology avert the World Water Crisis in the 21st Century?' was organized in Tokyo. A number of the presentations were later published in the Hydrological Sciences Journal, the official journal of the International Association for Hydrological Sciences.[11] Besides an introductory overview on the general global problem, this special issue contained papers on future prospects in important regions (Africa, South America, South-east Asia, China, Eastern Europe) as well as three papers on important aspects of hydrological science (including modeling on a regional and global scale and important issues involving the social sciences, perception of risk, mitigation of vulnerability).

In December 2001, an International Conference on Freshwater was held at Bonn to make a further input to the 2002 World Summit on Sustainable Development at Johannesburg and the 2003 World Water Forum in Tokyo. The Ministerial Declaration stated that 'three is still a need for a greater commitment to implement commonly agreed principles on water resource management'. Five key problems emerged from the Conference.

(a) the need to meet the water security problems of the poor

(b) the need for decentralization and wide participation

(c) the need for new partnerships

(d) the need for integrated water resource management involving all water users

(e) the need for improved governance at all official levels.

The Conference recommended priority actions under the three headings of improved governance (12 action items), mobilising financial resources (five action items). The report sets out the special roles of the individual group of stakeholders (governments, local communities, workers, NGOs, the private sector, the international community), in forming the new partnerships required.

It can be safely stated that the main options in relation to the future managements of water resources are now clear and that there is considerable convergence of agreement in relation to the basic principles to be followed. This represents a good beginning in tackling a key problem for the 21st century but it is only a beginning. The basic issues must be further clarified, they must be stated in clear unambiguous language, and they must be even more widely discussed and above all they must be implemented politically. This is a great challenge for all concerned but most particularly for water engineers and for politicians. Informed dialogue leading to an agreed course of action is a difficult process but it is rewarding if undertaken with mutual respect and above all it is necessary if the key problem of water resources development is to be resolved efficiently and with equity.

Throughout this discussion, stress has been laid on the necessity for persons from diverse backgrounds to work together. This is not easy. Whether at a social gathering or at a deliberative meeting, the requirements for good conversation are the same :

(a) a common language known moderately well by all participants.

(b) a common focus of interest.

(c) a willingness and an ability to talk clearly.

(d) an ability and a willingness to listen patiently.

The special jargon and the implicit assumptions of any cohesive group facilitate communication within that group but hinder communication with other groups.

The main problem in this regard is not the special terms whose meaning is not known to other groups but the words whose meaning differs somewhat from group to group so that viewpoints becomes distorted as in the case of a mistranslation. A real focus of interest is also of vital importance. Experience from interdisciplinary research within the natural sciences and between the natural and the social sciences indicates that such efforts are rarely successful unless sharply focused on a well-defined problem. As every teacher knows, the need to speak clearly is not only important for communication but also for the clarification of one's own thinking. As for listening, this must be a genuine attempt to understand and respect the viewpoint of the speaker and not merely a passive interval between bouts of speaking advocating one's own limited attitude to the problem.

The emphasis in this discussion has been on the need for improved management of water resources particularly in the developing world. This is so because this problem is one of the most daunting management problems facing the next generation in the engineering profession. However, the incorporation into engineering planning and management of what has been termed appropriate economics and appropriate ecology is valid in all types of engineering and in every type of society. The examples given above are intended to emphasise in relation to one area the basic principles that can and should be applied in other areas with appropriate emphasise and adaptation. In all areas of the management of water resources they are vital if the threatening crisis facing us in this field is to be averted.

To discuss the wide range of technological options available and the rationale for choosing between them would require a separate review. They vary from new and improved methods of data collection to methods of expanding the resource basis either by inter-basin transfer over long distances or by desalination. These constitute direct inputs of the engineer into the common project. The indirect, but equally important, input of the engineer is a willingness and an ability to co-operate with partners from different and diverse background in solving this common problem.

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REACTIVE POWER COMPENSATION BY STATIC VAR COMPENSATORS BASED ON SELF COMMUTATED TECHNIQUES.

By

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ABSTRACT

Over recent years the various types of Reactive power compensation has evolved as the technology has changed. Nowadays the most popularly used equipments employs Thyristors for fast and accurate control of the Reactive power produced.

This paper deals in comparison of various conventional reactive power compensation techniques. It also leads in derivation of equations for single phase Reactive power compensators. It will further give a concept of Reactive power compensation which can be considered as a backbone for the stable industry. The Voltage Source Inverter Reactive power compensator (VSI-SVC) is identified as the best circuit for development as a high power static VAr compensator. A basic design for this type of compensator is highlighted in this paper.

CONVENTIONAL REACTIVE POWER COMPENSATION TECHNIQUES

The brief description of VAr compensation techniques is given as follows [1].

The Synchronous Condensers

The Synchronous Condenser is basically an unloaded Synchronous motor connected to AC system. By varying the DC excitation current, the machine generated voltage can be made larger or smaller than the AC system voltage [2].

Synchronous condensers are very effective Reactive power compensators. The relatively slow response time typically 0.2 sec makes the synchronous condenser unsuitable for dealing with the effects of rapidly changing loads.

The Saturable Reactor SVC

The Saturable Reactor compensator consists of a number of magnetic cores operated in their saturation region. The SVC requires no imposed control system and consequently has a very fast response of the order of 0.05 sec.

The main disadvantage of saturable reactor SVC is that single magnetic cores generate large harmonic currents. However this problem can be overcome by connecting the cores in complex three phase arrangements.

Fixed Or Mechanically Switched Capacitors

Fixed or mechanically switched reactors and capacitor can be used to absorb and generate Reactive power. The main problem is that the VAr's produced is essentially fixed and the response of the switched units is slow being limited by the speed of mechanical switch used.

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The Fixed Capacitor-Thryristor Controlled Reactor (TCR)

For providing fast variable control of Reactive power, fixed capacitors are often used in conjunction with Thyristor Controlled Reactors (TCR) [2]. Response time in the range 0.02-0.05 sec can be achieved.

Each phase of the TCR consists of an inductor (Reactor) and two inverse parallel connected Thyristors so that each conduct on alternate cycles of the AC supply voltage. The equivalent circuit is shown in the figure 1.

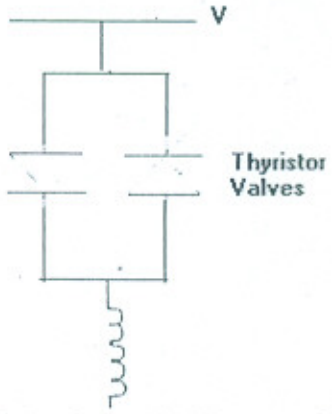


Fig.1 Thyristor Controlled Reactor SVC.

The Switched Capacitor-Thyristor Controlled Reactor (TCR-SVC)

The fixed capacitor as mentioned above can be replaced by a mechanically switched capacitor allowing a lower rated TCR to be used. The disadvantage is that the speed of response of the equipment is seriously impaired being limited by the mechanical switch used.

The Thyristor Switched Capacitor(TSC)-Thyristor Controlled Reactor (TCR) SVC

The problem of speed of response as described in previous section can be overcome if a Thyristor switched Capacitor (TSC) is used in place of a mechanically switched capacitor [3]. The equipment circuit is shown in the fig 2.

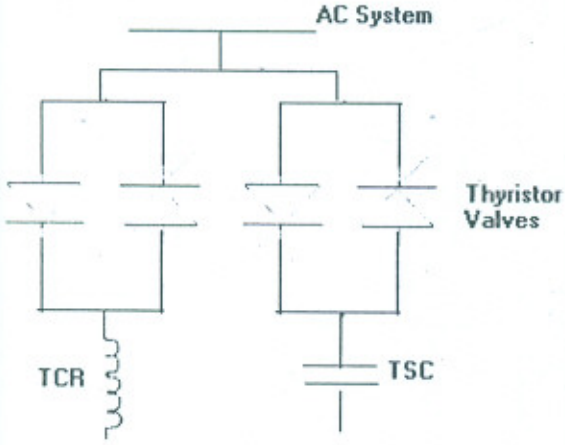


Fig 2. Circuit Of TSC-TCR SVC.

Unlike the TCR, the firing angle of the Thyristors used for the TSC must be accurately controlled to minimize the high inrush currents that can occur when energizing a capacitor. Ideally, thyristor gating is performed when the capacitor voltage and the AC system voltage are equal and the capacitor current is zero and occurs only at a firing angle of 90 degrees.

DEFICIENCIES OF CONVENTIONAL REACTIVE POWER COMPENSATORS

In sections 2.1 to 2.6 conventional Reactive power compensators are discussed briefly. The following table summarizes the main deficiencies of each type of compensator.

Reactive Power Compensator	Main Deficiencies.
Synchronous Condenser	Relatively slow response time typically 0.2 sec. Bulky and expensive. High maintenance cost.
Saturable Reactor	Interconnection of many reactor cores results in harmonics. Only able to absorb Reactive power.
Fixed or Mechanically Switched Reactors.	Reactive power produced is essentially fixed. Response time is slow.
Fixed Capacitor TCR SVC.	TCR must be rated to absorb VAr generated by the capacitor.Harmonic filters are normally required.
Switched Capacitor TCR-SVC	Speed of response is slow.
TSC-TCR SVC	Complicated control strategy required to minimize switching transients.

STATIC VAr COMPENSATOR BASED ON SELF COMMUTATED SWITCHING ELEMENTS

The term self commutated refers to the ability of the semiconductor switches of the converter circuit to be turned on and off in response to the signals applied to the controlling terminal. Force commutation, however refers to the device turn off by means of externally induced current zero's.

Reactive power compensators based on self commutated converter circuits offer three main advantages over conventional techniques [4].

1) The rating of the reactors and capacitors of the SVC may only be a fraction of that required for a conventional thyristor based compensator.

2) The fact that the switching elements of the converter circuit may be turned on and off at any time during their conduction period allows PWM techniques to be applied to eliminate harmonic currents produced by the SVC.

3) The Reactive power produced is less dependent on the magnitude of the AC system voltage enabling full output to be maintained at voltages significantly below the normal operating value making the SVC more suitable for use in weak AC power systems.

High voltage switching devices with negative voltage capability may become available in future as many devices with higher voltage and current capabilities. For high power advanced SVC's ,GTO (Gate Turn Off) thyristors are the preferred devices because of their higher voltage and current capability. Three types of commutated SVC exist.

1-The Unrestricted Frequency Changer(UFC)

2-The Current Source Inverter(CSI)

3-The Voltage Source Inverter(VSI)

The UFC-SVC and CSI-SVC require switching elements which can withstand negative voltages. The presently available high power semi-conductor devices for these circuits cannot withstand negative voltages meaning that a power diode must be connected in series with each switching device. The diodes will increase the overall cost of the equipment and additionally increase losses particularly if PWM (Pulse Width Modulation) techniques are employed. With the Voltage Source Inverter(VSI) SVC each switching element requires an antiparallel diode however diodes and switching elements do not conduct at the same time and therefore the associated losses are expected to be less.

Further to this the CSI and UFC circuits contain reactors whereas the VSI circuits contain a capacitor. It is observed that the resistance of power capacitors is significantly lower than that reactors. Therefore the losses are contributed by the capacitor of the VSI-SVC. Thus the VSI approach offers the greatest potential for development to high power.

SINGLE PHASE VSI-SVC

The simplest possible VSI-SVC is the single phase circuit. When viewed from the AC power system, the inverter circuit appears as an AC voltage source [1] which produces fundamental and harmonic voltages as shown in the figure 3.

Figure 3. Single Line Diagram Of VSI-SVC connected to AC Power System.

Principle Of Operation

When viewed from the AC power system, the inverter circuit appears as an AC voltage source which produces fundamental and harmonic voltages as shown in figure 3 .

The inverter circuit is controlled to produce a fundamental voltage in phase with the power system voltage. When the fundamental inverter voltage is greater than the AC system voltage, a leading (capacitive) current is drawn from the power system and therefore the circuit generates reactive power. When the inverter terminal voltage is lower than the AC system voltage the converse is true and the circuit draws a lagging (inductive) current and so absorbs reactive power. The harmonic voltages produced by the inverter cause harmonic currents to flow into the AC system.

Phase Angle Control

Under steady state operating conditions no exchange of real power takes place. Therefore the normal DC power supply used to feed the inverter can be replaced by a DC energy storage capacitor which simply provides the necessary commutating voltage. If the semiconductor devices of the inverter circuit are switched so that the inverter terminal voltage leads the AC system voltage by a few degrees, real power flows from the DC side of the circuit to the AC side of the circuit decreasing the capacitor voltage. The converse is true when the inverter output voltage (V_1) lags the AC system voltage (E).

Phase angle control allows the DC capacitor voltage to be varied which inturn varies the inverter terminal voltage and therefore the amount of reactive power absorbed or generated. In a practical SVC, a finite phase angle difference is maintained between the AC system voltage and inverter terminal voltage so that a small amount of real power is continually supplied to accommodate inverter losses [3].

Circuit Configuration

The single phase voltage source inverter circuit is shown in figure 4.

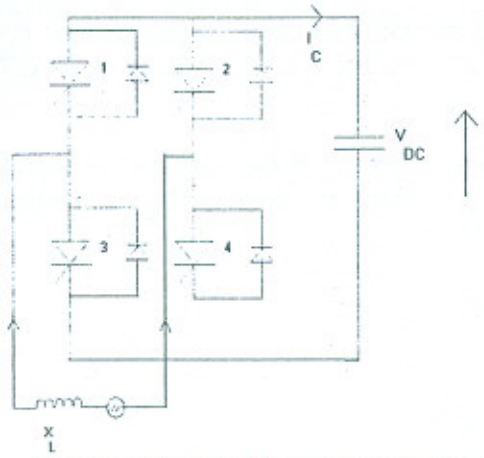


Figure 4.Single Phase Voltage Source Inverter.

The circuit consists of four self commutated semiconductor switches connected in a single phase bridge configuration with a capacitor connected on the DC side of the circuit. Each switching element has an inverse parallel diode connected to allow bi-directional current flow. The diodes are necessary to enable the circuit to draw an alternating current and to keep the capacitor charged. They also protect the semiconductor devices against negative voltages which may damage the devices. The inverter is connected to the power system by a transformer with a leakage reactance whose simulation is provided by an inductor.

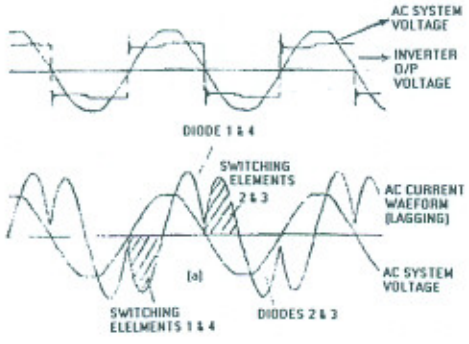
Simulator Model

A low power model simulator was designed using GTO thyristors as the switching elements. The circuit is shown in figure 4 [3]. A variable inductance was connected between the inverter circuit and the AC source to simulate the leakage reactance X_L of the transformer. The GTO gating signals were derived from the AC source voltage using a step down transformer in order to keep the inverter terminal voltage in synchronism. Phase angle control was achieved by comparison of the AC source voltage with a square wave voltage of variable magnitude lagging the source voltage by 90 degrees. The GTO thyristors were turned on by the application of a current pulse and turned off by switching a negatively charged capacitor between the gate and cathode so that current was drawn from the gate.

The results were obtained with the inverter supplied by a DC generator and a large charged capacitor of 12000μF. The AC supply voltage was maintained constant at 35.4 V_{rms}. The DC generator voltage was varied over the range 20V to 50V. Circuit inductance values of 50mH,100mH and 150mH were used. The following measurements were taken.

1. The magnitude of the Reactive component of AC current.
2. The magnitude of the AC current harmonics .
3. Waveforms of the AC current, the AC supply voltage and the inverter output voltage.

The tests were repeated with the capacitor voltage varied over the same range by control of the GTO firing angle.



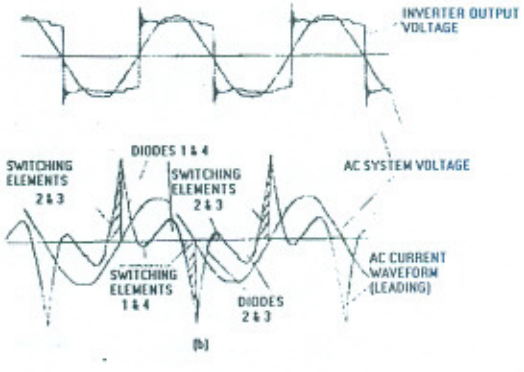


Fig 5. Typical Voltage & Current Waveforms
(a) Lagging AC Current Operation
(b) Leading AC current Operation

Figure 5 shows typical voltage and current waveforms obtained with the large capacitor in both lagging and leading modes of operation and shows the current division between the diodes and GTO thyristors of the circuit.

Figure 6. shows the fundamental current and lower order harmonics as the DC voltage was varied. Even order current harmonics were negligible as expected since the square wave voltage waveform produced by the inverter.circuit contains no even harmonic components.

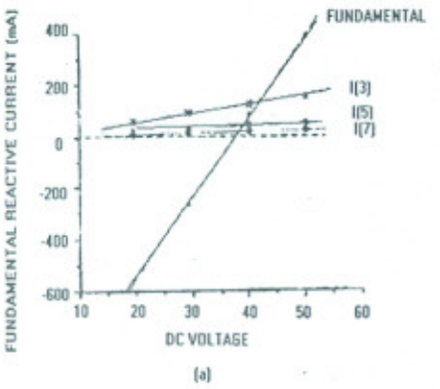


Figure 6. Fundamental And Harmonic AC Currents. Full Range Test Results.

FUNDAMENTAL AND HARMONIC COMPONENTS OF AC CURRENT

The AC current is determined by the voltage across the inductance of the circuit transformer [4]. Any continuous periodic waveform may be described by a Fourier series which may contain a DC component and a number of sine and cosine terms. The general expression for the Fourier series is :

$$F(x) = a_0/2 + \Sigma\, a_n \mathrm{Cos}nx + b_n \mathrm{Sin}nx$$

Fourier analysis is performed on the square wave voltage to determine the fundamental and harmonic components. By inspection the inverter output voltage is even with no DC component and therefore only the a_n term exists.

Fundamental rms inverter terminal voltage=$0.9V_{DC}$

n^{th} harmonic rms inverter terminal voltage = $\dfrac{0.9V_{DC}}{n}$

The AC line current is limited by the Reactance $n\omega L$ of the circuit transformer. It is assumed that the AC system busbar has infinite capacity and therefore the AC voltage is sinusoidal and of constant magnitude (E) and frequency. The fundamental and harmonic currents are there-fore given as

$$\text{Fundamental Reactive Current} = \frac{E - 0.9V_{DC}}{j\omega L}$$

$$\text{Harmonic current} = \frac{0.9\,V_{DC}}{n^2\omega L}$$

where n = 3,5,7,9,11 etc.

Figure 7. shows the fundamental and 3^{rd} and 5^{th} AC harmonic currents predicted by the above mentioned equations. For L = 100mH and E=$50/\sqrt{2}$V for a range of DC voltage values. Also included are the simulation results obtained with the large (12000μF) capacitor [1].

There is a very good correlation between the measured and predicted results particularly between harmonic currents.

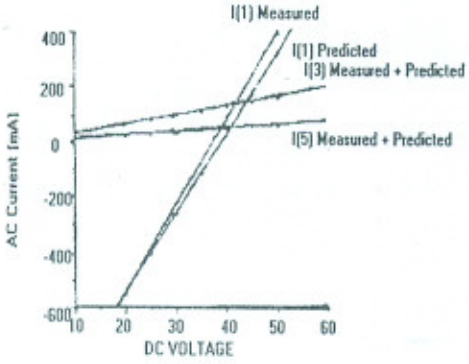


Figure 7. Comparison of Measured & Predicted AC Fundamental & Harmonic Currents.

AC Current Waveform

Expressions describing the AC current Waveform are found by considering the voltage across the transformer inductance over each 180 degree period. Semiconductor switches 1&4 are closed over the period $0< \omega t < \Pi$ and semiconductor switches 2&3 are closed over the period $\Pi < \omega t < 2\Pi$ .This pattern then repeats after every 2Π .

Over the period $0 < \omega t < \Pi$ the voltage across the circuit inductance is

$$V_L = \sqrt{2}\, E \sin\omega t - V_{DC} = L\frac{di}{dt}$$

Solving this diffential equation yields

$$i(t) = \frac{-\sqrt{2}E\cos\omega t}{\omega L} - \frac{V_{DC}t}{L} + K$$

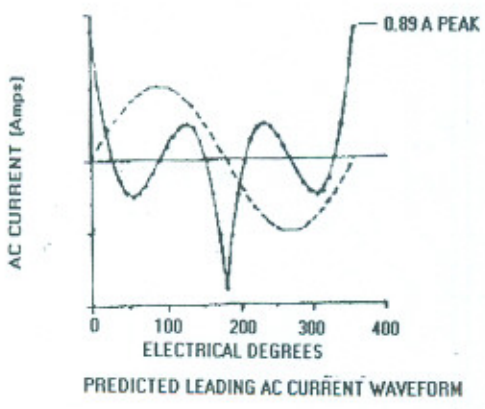
where K is the constant of integration. $i(t) = 0$ at $\omega t = \Pi/2$ because the fundamental and all harmonic currents pass through zero at $\omega t=\Pi/2$.

Therefore $K = \frac{V_{DC}\Pi}{2\omega L}$

The current waveform over the period $0<\omega t<\Pi$ is therefore given by.

$$i(t) = \frac{V_{DC}\Pi}{2\omega L} - \frac{\sqrt{2}\cos\omega t}{\omega L} - \frac{V_{DC}t}{L}$$

Using the above equations the current waveform has been predicted and in figure 8 the predicted and simulated results for currents are compared.



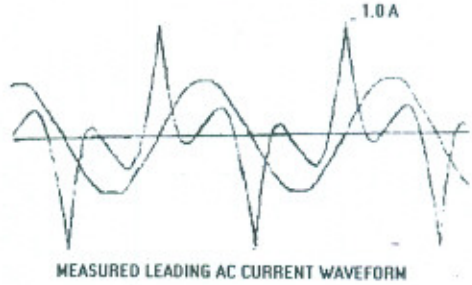


Figure 8. Predicted & Measured AC Current. [1]

DC Capacitor Current

The capacitor current is equal to the AC current over the period $0 < \omega t < \Pi$ and the negative of the AC current over the period

$\Pi < \omega t < 2\Pi$. The peak capacitor current can be obtained by substituting t = 0.

$$I_t \text{ off} = \frac{1}{\omega L}\left[\frac{V_{DC}\Pi}{2} - \sqrt{2}\,E\right]$$

Figure 9. shows the predicted capacitor current waveforms . In both cases the capacitor current is repetitive.

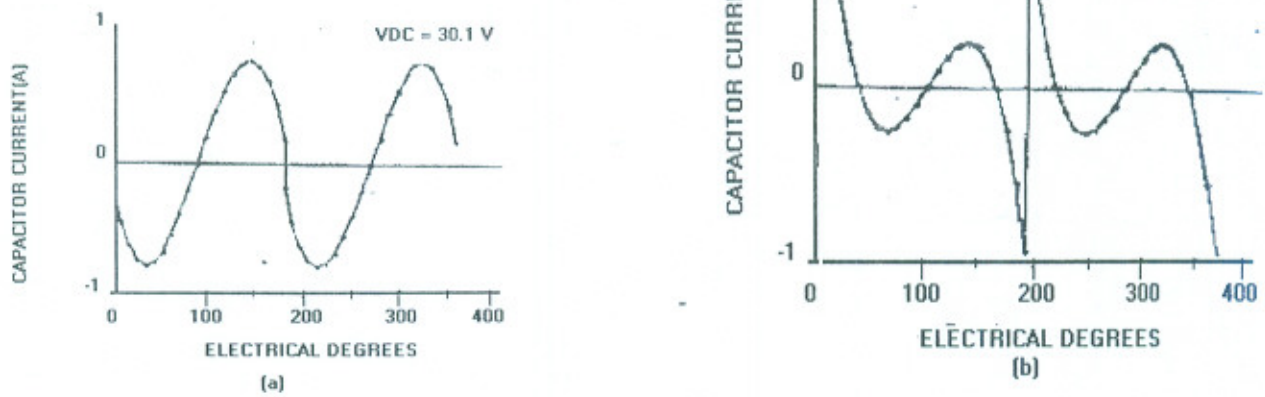


Figure 9. Predicted DC Capacitor Current.
(a) Lagging AC Current Mode
(b) Leading AC Current Mode

DC Capacitor Voltage

The DC capacitor voltage is given by

$$V_C = V_0 + 1/c \int i\,(t)\,dt.$$

Where V_0 = capacitor voltage at t=0

After integration and further derivation the final equation comes out as

$$V_c = V_{DC} + \frac{1}{\omega^2 LC}\left[\frac{2\sqrt{2}E}{\Pi} - \frac{V_{DC}2\Pi}{12} + \frac{V_{DC}\Pi\omega t}{2} - \sqrt{2}E\sin\omega t - \frac{V_{DC}(\omega t)^2}{2}\right]$$

Figure.10 gives the predicted (calculated) capacitor voltage waveforms. The equivalent simulation results are also given for comparison.

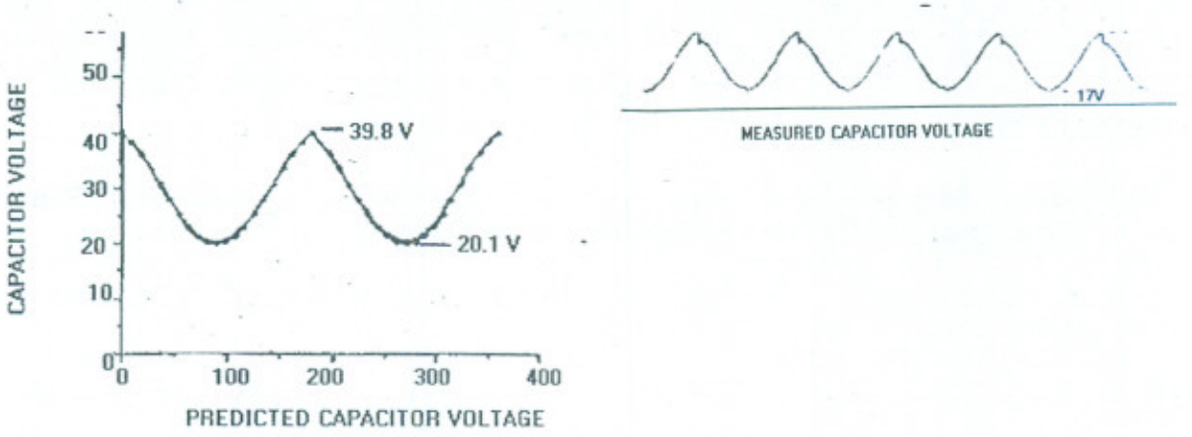


Figure 10. Comparison of Predicted & Measured Capacitor Voltage waveforms.

COMPARISON OF MEASURED AND PREDICTED CURRENT

Figure. 11 gives a comparison of measured and predicted values of fundamental current and 3rd and 5th harmonic currents .There is a good correlation between the simulated and predicted AC current particularly the 3rd and 5th harmonic components.

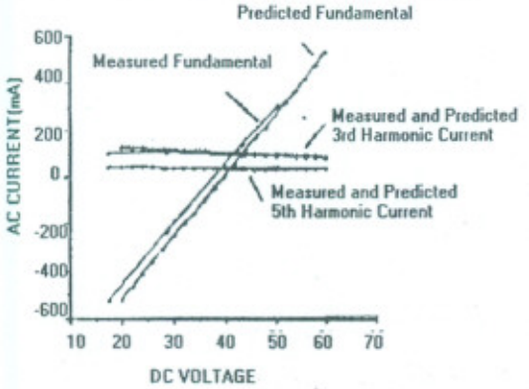


Figure 11. Comparison Of Measured and Predicted Fundamental and Harmonic Currents.

THE SINGLE PHASE VSI-SVC IN POWER SYSTEM APPLICATION

Electrical power is normally generated and transmitted as 3 phase AC and therefore reactive power is normally required to be supplied to all three phases of a power system. To overcome this problem three single phase VSI-SVC's can be connected to the power system by a transformer containing delta connected winding [6]. The triplen harmonic currents would be eliminated from the AC lines under balanced conditions [4].

CONCLUSION

The operation of the single phase voltage source inverter based on SVC has been investigated by simulation and mathematically. The ability of the circuit to both absorb and generate reactive power has been observed. It has been further observed that the switching elements (GTO'S) require self commutation capability to enable the circuit to generate reactive power.

Further to this stand alone single phase VSI-SVC is not practical for 3 phase application unless unbalanced VAr compensation is required.

In high power circuits the onstate voltage drop of the semiconductor devices would be negligible in comparison with the intended operating voltage of the SVC.

It is proposed that in practical field the subsequent models can be improved in this respect by replacing the GTO thyristors with the MOSFET's so as to cover the onstate voltage drops.

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OBITUARIES

May their souls rest in Peace

1. Engr. Ashraf Ghumon
   S.D.O. Irrigation and Power
   Department, Punjab

2. Engr. Masih-ullah Khan
   Former President
   Pakistan Engineering Congress
   (1983 – 1985)

CRITICAL APPRAISAL OF HIGHWAY CONSTRUCTION AND SALUTARY SUGGESTIONS

By

Engr. Shaukat Ali*

SYNOPSIS

AASHTO itself has admitted in its own research work that both the structural layer coefficient and the Modulus of Resilience of asphalt concrete are temperature dependent and become highly variable with change in temperature. Our designers continue to take layer-coefficient as constant throughout the vagaries of weather taking its value as 0.44 as initially adopted by AASHTO Design Committee because of misjudgment. Modulus of Resilience is also being adopted for pavement design purposes at a fixed temperature of 20°C (68°F) ; the same temperature at which layer coefficient was assumed as 0.44. Pavements designed on wrong foundation cannot behave rightly and must misbehave and show signs of distress earlier than design life.

Asphalt concrete which has the potential to perform satisfactorily in countries where average temperature does not exceed 20°C, miserably fails and ruts in a hot country like ours where ambient temperature for as long as 3 months in the major part of Pakistan remains above 45°C and asphalt pavement temperature above 70°C.

AASHTO specifications and highway materials are purposely so designed that they give best results by deploying machinery.

Imported machinery does not suit such developing countries like Pakistan who do not have enough dollars of their own and have to beg and borrow from IMF and World Bank as loan. AASHTO specifications are World Bank and IMF-oriented and suit G-8 countries who manufacture their own machinery. To further aggravate the situation World Bank throws us into the abyss of inferiority complex by giving us ex-gratia such super riding quality indicators as IRI's and convinces us that we cannot build good roads without their machinery and therefore cannot survive without their loan.

Seeing through their stratagem, I have endeavored to propose a loan free highway construction strategy using every thing indigenous and local ; local machinery, local manpower, local expertise and local materials requiring no loan-demanding feasibility reports, nor machinery nor spares, nor experts. I have attempted to over throw the yoke of white-man's hegemony as well as curse and imprecation of degrading morass of loans by following our own tried and tested methods of construction we have thrown into oblivion in the name of pseudo-progress.

I have given the sum total of my experience and study as alternative to what we are blindly following in road construction as the so called state of art which least suits us. It is for the readers to judge how far I have succeeded is my endeavor.

CLARIFICATION

From the very outset I would like to point out that this Critical Appraisal does not bind itself to asphalt concrete, it covers the total pavement structure of sub-base, aggregate base and asphalt concrete, in other words every thing above earthen embankment and sub-grade. It

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* FIE (Pak), FEDIO (World Bank)

pre-supposes full compaction of sub-grade as well as the embankment precluding the possibility of its settlement either from ingress of water from top or egress from below. It also presumes that the proposed sand filled macadam, water bound macadam and bitumen filled macadam shall be hundred present compacted to prevent any possibility of settlement subsequently anywhere.

It also assumes that fresh specifications shall be written for surface treatment, water bound macadam and sand filled macadam. This is because the type of work I have specified and proposed has not been done before either by any provincial department or other agencies in Pakistan and abroad to the best of my knowledge.

I do not endorse the surface treatment being carried out presently in various departments and authorities nor do I endorse any water bound macadam being specified in NHA specifications. Sand filled macadam is however altogether a new item.

Because of absence of in depth know-how of water bound macadam and surface treatment, the quality of work being got carried by the Consultants under the aegis of NHA, is too poor to stand the test of time. Tomorrow these very Consultants would blatantly declare that they have tried much trumpeted water bound macadam and surface treatment and they miserably failed.

Asphalt is a Jungle and in a Jungle no laws apply. And yet we have the imbecility to order it to obey mathematical laws. Are we in a proper frame of mind ?

More than a decade ago I had the audacity to highlight certain vital aspects of highway construction in Pakistan which were, according to me, generally responsible for poor performance of roads being built under the aegis of supposedly most technical highway construction agencies using state-of-art specifications under the supervision of expatriate and foreign experts.

My submission was not heeded and the pace of construction, following the same specifications, the same modus operandi of construction and the same materials proceeded as before. Before the completion of M-2 National Highway Authority admitted in a seminar for the first time that all the roads recently built by NHB / NHA were either gradually showing signs of rutting or had already rutted. It was finally concluded that rutting can not be stopped without imposing an embargo on plying of heavier axles and without establishing a network of weigh-bridges.

The most unfortunate aspect of highway construction is that we are building ruttable roads on borrowed money. And then we shall borrow money for import and establishment of weigh-bridges and then we shall borrow money for milling ruttings and milling machines and lastly we shall borrow money for expensive overlays over the milled highways. This is because asphalt roads shall invariably require overlays after about ten years. A vicious circle of borrowing shall start without end. Where have our wits gone ? Is there no body to say that the king is naked and not wearing any clothes ? Very learned, wise, astute and exotic consultants have brought this point home to the king that the clothes he is wearing are too fine to be seen and only the fools shall object to it. I have heard some our technical doyens say that asphalt concrete cannot rut ; our people do not know how to make and lay it.

Since 1990, construction scenario has not changed and there is need to critically reappraise highway construction and adopt sustainable alternatives as far as possible indigenously. The areas of construction which I intend to highlight for critical appraisal are :

(1) Asphalt Concrete (2) Aggregate Base

(3) Sub-Base (4) Pavement Designs

Asphalt Concrete

Though Asphalt Institute was established in 1919, asphalt concrete was being used by various states of U.S.A. as a road paving material even before its establishment. It was however mostly the Asphalt Institute Staff who developed Job-Mix-Formulae for manufacturing asphalt concrete, especially its such notables as Provost Hubbard, F. C. Field and Francis Hveem.

Bruce Marshall, a seasoned Material Engineer of Mississippi Highway Department in 1940, introduced a new method of preparation of JMF, which was substantially different from Hubbard-Field and Hveem methods and had the blessing of U. S. Corps of Engineers. Because of its simplicity and consistent results in various states Marshall Method of Mix design soon became popular and began to be used extensively not only in U.S.A. but also in Europe, Asia and Africa.

Job Mix Formula

Job mix formula or JMF is a method for determining optimum bitumen content which could give durable and stable asphalt concrete. In order to maximize durability and to minimize weathering and bleeding both the air voids and voids filled with asphalt are also kept within certain specified limits. For detailed mix design different mixes are made with pre-tested well-graded aggregate starting from 2.5% bitumen to about 5.5% increasing by 0.5% for each mix. The mixes so formed in the laboratory are tested in respect of the following and results are drawn on graph with bitumen content as abscissa.

(1) Stability (2) Air Voids (3) Unit Weight

(4) Voids Filled with asphalt (5) Voids in mineral aggregates

Design bitumen contents is taken as an average of 3 bitumen contents at maximum stability, maximum unit weight and median of specified air voids.

In explaining the process of developing JMF the idea is to point out that there is nothing in the JMF, manipulation of which could help us in getting a rutting-resistant asphalt concrete. Whatever we may do if we strictly follow the Marshall Mix Design Parameters and prepare a JMF accordingly, there shall be no reduction in rutting in our environs. In sultry summers our ambient temperature goes as high as 48°C to 50°C and road services temperature rises to 70°C to 75°C. At this temperature asphalt concrete becomes softer and gradually succumbs under the heavy wheels. At low temperatures it becomes harder and behaves elastically and its behaviour can be predicted even mathematically by mechanistic analysis. Upto about 68°F (20°C) asphalt concrete follows Hook's Law of stress being proportional to strain but at higher temperature stress / strain ratio known as elastic modulus or modulus of resilience falls drastically as indicated below by drop of Modulus of Resilience values with increase in temperature :

Temperature	Modulus of Resilience (Mpa)
0° C	30,000
10° C	16,000
20° C	4,500
25° C	2,800
30° C	1,000
40° C	500

From the above what would be the drop of MR upto 75°C can be well imagined. AASHTO Design Committee who adopted the layer coefficient of asphalt concrete in cold temperature of Chicago as 0.44 could not visualize that road service temperature can rise as

high as 75°C. Adoption of layer coefficient of 0.44 even in our torrid environs by all the consultants in Pakistan is one of the major reasons of premature failure of roads.

- So long as an effective asphalt modifier is not developed, use of asphalt concrete is fraught with the imminent danger of rutting wherever heavy axled traffic is predominant. We should not foreget that asphalt roads are bound to rut with the passage of time as a result of cumulative irreversible strain, which develops at high road service temperature even under standard axles. Another aspect which is not being considered while insisting on the use of asphalt concrete is that during a period of 10 ± 2 years asphalt concrete as a consequence of weathering and oxidation develops reveling and surface cracks and its riding quality drops irrespective of the ESALS passed. Thus overlay becomes necessary not because of design life alone but also because of weathering and oxidation.

The question is should we still continue to lay asphalt concrete when we know it is not cost effective and when it is bound to fail and misbehave and when we shall not be able to provide overlay over all of our roads without foreign loans.

Aggregate Base

The primary requirement of aggregate base is that it should have high stability or in simpler words it should offer great resistance to displacement of its constituent stones under the displacing traffic wheel at high speeds. This quality of aggregate base becomes visible if traffic is allowed to ply directly over the finished base. The displacement could be in the shape of early, development of potholes or finished surface may adopt the shape of a sine curve AASHTO specified base does not emphasize this quality as it presupposes to be overlaid with sufficiently thick asphalt concrete. Aggregate base or untreated base as per AASHTO specifications is nothing more than a small percentage of stone aggregates suspended in the matrix of fine aggregates most suited for laying through paver-finisher after adding modicum of moisture in a pug-mill of an asphalt plant. As such AASHTO aggregate base is machine oriented and machine friendly, which though well graded, does not have any interlocking and inter-particle friction. For this very reason the base material we are laying does not have much structural value though it manages to give a CBR of 80. Such a base develops pot holes easily if over-laid with surface treatments. For lack of adequate stability and almost no interlocking, it cannot have much structural strength and as such it does not suit us, as it cannot make durable roads. For us structural strength and durability are more important than the gradation it emphasizes. The only purpose of gradation is that it helps in achieving compaction with fewer passes and lesser efforts. Since we cannot afford less durable roads we should not continue to lay base which does not suit us.

Aggregate Sub-Base

The primary requirements of a sub-base apart from distribution of wheel load over a wider area of sub-grade is that it should act as a moisture-rise barrier against capillary rise and salt-rise barrier against salts present in the sub-grade and at the same time it should keep the sub-grade dry and strong by taking up its moisture as a blotting paper or by allowing the moisture reaching the sub-grade either from top or bottom getting drained off towards sides. These rudimentary functions of sub-base do not get specifically emphasized in the AASHTO specifications with the result that durable roads do not get built. As against the above, the requirement of AASHTO sub-base is that the fines passing sieve No. 40 should have liquid limit not more than 25 and plasticity index not more than 6. According to this provision ordinary A-4 soil meeting this requirement can be added in the sub-base to great detriment of its requirement of acting as a barrier to rise of salts and moisture. This would also drastically minimize its drainability. Since A-4 soil lying within liquid limit 25 and plasticity index 6 will be as per specifications, no Consultant would be able to raise any objection. This limitation also applies to

aggregate base where drainability is not required but some sort of cementing cohesion or cohesiveness is needed which can only be provided by a calcareous stone dust or rock dust. Hence the provision of liquid limit and plasticity index does not help us both in case of sub-base and aggregate base and tends to make inherently faulty roads. There is therefore, need for different specifications suiting our environments.

Pavement Design

We are spending billions of rupees using asphalt concrete as the primary structure component of our highways and so far we have failed to arrest rutting. In spite of its continued ruttability or strong proclivity to rutting we have never seriously thought of using alternate materials which could resist rutting and be simultaneously cost-effective.

Use of Asphalt Concrete as major structural component of flexible pavements is highly deep rooted. Its roots go deep into the AASHTO Road Test when AASHTO Design Committee in view of its better performance in Illinois, Chicago assigned it the highest layer coefficient value of 0.44 not keeping in view the fact that this performance was primarily because of cold climate where temperature mostly remained below 20°C. Since all the good performance was attributed to asphalt concrete relatively much lower structural values were assigned to the crushed rock as base and sandy gravel as sub-base. The Committee evidently misjudged because the layer coefficients do not remain constant with temperature. It is now, an established fact and recognized by all that the layer coefficient values are temperature dependent as shown below.

Temperature	Layer Coefficient
0° C	0.60
10° C	0.56
20° C	0.44
30° C	0.30
40° C	0.25

Our ambient temperature even in Islamabad goes as high as 46°C when it exceeds 50 in the down country and layer coefficients fall drastically as can be concluded from above. What happens to a road pavement at high temperature in summers can be visualized from the following design actually adopted on a down country section of N-5.

	Design Structural Value	Structural value in hot summers
Wearing Course – 50 mm	2 x 0.44 = 0.88	2 x 0.10 = 0.20
Asphaltic Base Course – 240 mm	9.5 x 0.40 = 3.80	9.5 x 0.10 = 0.95
Aggregate Base Course – 300 mm	12 x 0.14 = 1.68	12 x 0.14 = 1.68
Sub-Base – 150 mm	6 x 0.11 = 0.66	6 x 0.11 = 0.66
	Structural Number = 7.02	Structural Number = 3.49

A pavement which was supposed to require a structural number of 7.02, would surely fail at structural number 3.49. This is what is happening on asphalt concrete dominated pavements.

Mechanistic Design

Near the end of the second millennium, analytical method of pavement design also known as mechanistic design began to be employed considering asphalt concrete as an elastic material in preference to AASHTO Design.

In mechanistic design value of modulus of resilience is again being taken at about 20°C as was done when evaluating the layer coefficient of asphalt concrete by the AASHTO Design Committee. This adoption might be generally true for U.S.A. and Europe but cannot be applied in our case since our roads remain very hot for almost 3 months without any respite. As can be seen from below, modulus of elasticity drops with temperature. Results compiled from AASHTO Road Test were based upon actual testing and these were applicable to similar environs, similar climate and similar loading. Unfortunately, however, these results and calculations derived therefrom were rampantly applied to diametrically opposite climates and the result is evident in the from of road failure and rutting.

Temperature In °C	Modulus of Resilience (Mpa)	(Psi)
0	30,000	(4,350,000)
10	16,000	(2,320,000)
20	4,500	(625,500)
25	2,800	(406,000)
30	1,000	(145,000)
40	500	(72,500)

From the above it can easily be imagined what would be the extent of drop of modulus of resilience or elasticity when the asphalt pavement temperature reaches 75°C. The drop in modulus of resilience at such high temperature as 75°C would be several hundred times that at 20°C. Actual strain in asphalt concrete would increase as many times as its modulus drops.

This excessive strain would be irretrievable or in other words permanent in the form of rutting because of plastic settlement under the wheels.

As per current designing practice only fatigue cracking is considered as would result from axle load but strains produced from high temperatures are completely ignored. Environmental or temperature stresses are too excessive to be ignored. Mechanistic design therefore, cannot help us nor can all the plethora of computer models from Australia to Europe when the pavement temperature rises as high as in our case, not for a week or fortnight but for months together, from May to end of July and sometimes middle of August.

This also goes to prove that the design Committee who assigned average layer coefficients of

0.44	for Asphalt concrete
0.44	for Crushed Road Base
and 0.44	for Sub-Base

was only correct for the cold climate of Chicago alone as those values could not be applied to locations where the road temperature becomes very high. I pointed this in 1980, in my technical paper No. 41 entitled *"Highway Construction – Problems specific to Pakistan"* published by Pakistan Engineering Congress on the occasion of holding of a Seminar on Construction Industry of Pakistan.

No body in Pakistan has the audacity to say that AASHO was wrong nor any body else can imagine that and that is why every body from Asphalt Institute to Australia has assumed the value of Modulus of Resilience of Asphalt "E" as 3103 Mpa. This is equivalent to 450,000 psi which is modulus of elasticity of asphalt concrete at about 22°C. For Pakistan it is too low to be considered as pavement temperature except in winter. (see NTRC publication No. 228)

The factual position is that at high temperatures asphalt concrete does not remain elastic. Similarly when the sub-grade gets over moisturized during incessant monsoon rains it

again does not remain elastic. Hence the application of the elastic theory in our case is too fraught with danger to be safely applied. I wonder why all the technical pundits and doyens of our technical institutions did not protest against its continued use.

Our torrid environs are not occasional to allow us to apply only temperature corrections. They persist as long as 3 months. As such temperature correction cannot be as reliable as designing the pavement in the worst of loading conditions and severest of weather.

Some of our Senior Engineers have misgivings that asphalt concrete is being extensively used in the vast expanse of U.S.A. and some of its areas are as hot as ours and how come they are not feeling uncomfortable. The answer is that weather conditions every where are different. As per internet information the maximum high-ups in temperature in Arizona during the month of June do not exceed 110°F or 43°C. This temperature is not as high as ours. Moreover we are still using thick asphalt concrete top pavement layers in spite of frank admission of NHA that most of its roads have rutted and other are likely to rut soon unless plying of heavy axle loads are stopped through legislative. It is most unfortunate that we are wasting billions of dollars on ruttable asphalt concrete and still want to continue to use it thinking perhaps that we have no other alternative.

Marshall in his design for asphalt concrete Job-Mix-Formula adopted the pavement temperature which was the worst and the highest in his judgment i.e. 60°C. As per American conditions adopting 60°C as the road pavement temperature for determining the stability of asphalt concrete was vitally important because considering stability at lower temperatures like mechanistic design would have been fallacious and unreliable. For American weather conditions adopting 60°C as the road pavement temperature would give far more reliable mechanistic design. But the problem at this temperature is that the premise that asphaltic concrete is an elastic material and stress is proportional to strain does not hold good and as such mechanistic design cannot be applied. The myth of mechanistic design and structural superiority of asphalt concrete as strongest pavement component as was wrongly judged by the AASHTO Committee gets fully exposed and in this milieu asphalt concrete does not deserve to be given as high structural number as 0.44 when in torrid summers it does not exceed 0.10.

Marshall, Hubbard Field and Hveem were far more realistic and intelligent engineers than AASHTO Design Committee because they did not propose the temperature for determining Asphalt Concrete stability as low as 20°C. They proposed 60°C as it was the actual pavement service temperature and the same should have been adopted by the analytical designers.

From the above it can safely be concluded that so far as countries as hot as ours are concerned it will never be wise to bank on asphalt concrete and to search other materials and method of construction which come up to our traffic and weather requirements.

If mechanistic design is to be adopted in any case we should not only tal : into consideration the actual pavement temperature for the region we are building but shoulc also take into account the possibility of the sub-grade getting over moisturized in summer or winter rains. We should, therefore, adopt the modulus of resilience of sub-grade in the worst condition as is done in case of standard method of determining the CBR. It is the soaked CBR, which is always used and it is the soaked sub-grade and its modulus of resilience in soaked condition, which can give the realistic mechanistic design.

The fact, however, is that at as high a temperature as 70°C, asphalt concrete does not remain elastic and when the sub-grade is also over moisturized, it loses its elasticity and the entire concept of analytical design ends in nothing else but fiasco. And we are left with no choice but to think of an empirical design rationally evaluating the results of AASHTO Test and giving new values to layer coefficients of sub-base and crushed rock base. It is the sub-base and crushed rock base, which actually take the traffic load but their structural contribution has

been immensely belittled and depreciated. The structural contribution of aggregate sub-base and base is not affected by temperature and if we can keep the sub-grade always well drained off by maximizing drainability in sub-base or by provision of window drains or sky-lighting, virtual structural contribution of sub-base and aggregate base would be much more than asphalt concrete.

The traffic load is ultimately to be taken by the sub-grade. Sub-base and base perform the pivotal role of spreader of traffic load over a much greater area either through simple application of Rankine's Theory of spread of load at 45° or through Boussinesque Pressure Bulb Theory. In our eagerness to have exact stress-strain analytical solution with the aid of computers we abandoned scores of successful empirical methods and have fallen into the abyss of rutting and highly unsatisfactory analytical designs, which cannot give us durable and lasting roads.

Durability of Roads may not be that much important to U.S.A. and the West because they always have lot of money to apply another overlay when we, because of weak economy, are mostly passing through a state of impecuniosity and acute financial crunch.

In the above milieu, what should be done by us and what are indigenous solutions ? What I have said so far is only the prelude, the real dissertation of to day is the indigenous solutions which I would endeavour to highlight in as much detail as possible in what follows.

Salutary Suggestion

From the very outset I would like to clarify that all my salutary suggestions have indigenousization as the prime mover. We must use our own materials, our own manpower and whatever machinery we manufacture or can manufacture. We must discard imported machinery except what we already have or except some indispensable units like excavators and graders. Another exception would be when there is extreme urgency like floods or war etc. Sustainable indigenousization in construction whenever and wherever possible and feasible is vitally important and it is the only way to shake off the yoke of foreign loans.

It is with this in mind and for the sake of the following aspects that the road friendly alternatives are being suggested for

- Economizing in construction for more durable and lasting roads.
- Substantial reduction in maintenance cost.
- Maximizing deployment of local manpower and indigenous machinery.
- Encouraging manufacture of local highway construction oriented machinery.
- Complete elimination of rutting on new construction.
- Developing new construction materials according to new specifications and setting trend thereof.
- Indigenousization of highway construction from start to finish.
- Elimination of milling. Plethora of milling machines are sporuting from Japan to Europe and U.S.A. and their rapid development clearly shows that rutting is on the increase even in the cold countries what to speak of hot countries like us.
- Minimizing expatriate consultancy.
- Minimizing dependence upon I.M.F. and other foreign loans for highway construction.

- Maximizing used of large reserve of nullah and river-run gravel as hand broken stone thus economizing in the use of electricity and providing employment to teeming toiling land-less masses who migrate to cities and towns in search of jobs.

As explained earlier the conclusion drawn from AASHTO Road Test by AASHTO Design Committee and the layer coefficients assigned to asphalt concrete, crushed rock and sands gravel were correct in winters as well as summers of Chicago. But these could not be applied to hot regions of Arizona and Mexico where road pavement temperature was not less than 60°C. Its blatant use in Pakistan where road pavement temperature even exceeds 70°C was equally wrong. Such technical doyens as Hubbard Field and Hveem of Asphalt Institute and Bruce Marshall of Crops of Engineers knew it very well that the road pavement temperature rises that high and that's why Marshall adopted 60°C as the temperature for Asphalt Concrete for stability. Since this temperature had been adopted by Asphalt Institute and Marshall in forties, it was also necessary for the AASHTO Design Committee to assign layer coefficient keeping in view at least 60°C pavement temperature. When layer coefficient value of asphalt concrete drops drastically at 60°C, value of layer coefficient of sub-base and aggregate base would increase automatically for the same structural number. For the same reason layer coefficient values of sub-base and base need to be revised keeping in view the fact that it is the sub-base and base which spread the traffic load over larger area of sub-grade. It was also an untenable assumption that only asphalt concrete makes major structural contribution while sub-base, base and surface treatments contribute very little.

Scores of roads built in Pakistan, N.W.F.P., Sindh and Baluchistan as per old method of construction of water bound macadam and surface treatment are taking the brunt of traffic for years together when roads built as per so-called latest state-of-art could not survive even a few years after construction.

We can however, continue to provide asphalt concrete in thickness not exceeding 2" as wearing course on roads likely to be plied over by cars and light vehicles within metropolitan limits and city and town areas or on such roads where axled traffic is not expected to travel.

The Alternatives

In view of high cost of construction of asphalt concrete and asphaltic overlays, we are left with no choice except to resort to high cost-effective, easy-to-maintain, durable and sustainable methods of construction with altogether new specifications most suited to our environments. I am, therefore, proposing the following indigenous, local resource-friendly methods of construction as alternatives to both asphalt concrete as well as AASHTO specifications for sub-base and base. I would therefore propose the following :

- Sand Filled Macadam as sub-base.
- Water Bound Macadam as aggregate base.
- Semi Grout penetration as asphaltic base.
- Multiple Surface Treatment as wearing surface.

Sand Filled Macadam

With increase in development activities, our consumption of stone-aggregate has tremendously increased as compared to a few decades ago. Our natural stone reserves at Sargodha and Texila are fast depleting. Quarries nearer to Lahore at Shahkot and Sikhanwali have already reached the ground level. With exorbitant increase in cost of electricity crushed stone is becoming more and more expensive. Moreover crushing inherently lacks inter-particle

friction or interlocking which imparts immense structural strength to pavements. For maximizing interlocking in stone aggregates. It is necessary to encourage crushers or contractors to produce hand broken stone from large pristine reserves of river-run and nullah-run boulders, shingle and gravel which shall have not only excellent interlocking properties but most salutary Los Angeles, sulphate soundness and impact values.

For Americans and expatriate consultants hand-breaking is both unthinkable and retrogressive but we know that our manpower had been doing this and even now can deliver the goods. River-run water-borne hand broken stone is a highway construction material nonpareil which can give us rutting-free, high durable and lasting roads having minimum maintenance cost. This hand broken stone is least machinery-friendly since it can neither be laid through paver-finisher nor can be graded because of its inborn resistance-to-displacement and resistance-to-deformation.

On the basis of my forty four years extensive experience, keen observation of highway construction and performance of roads built then and being built now. I feel no hesitation in proposing a far cost effective to construct and to maintain alternative to the present system of construction in vogue in Pakistan. The sub-base would comprise of hand broken river-run boulder laid over a modicum of sand and compacted dry as per water-bound macadam and crevices filled with cheapest available sand. Compaction is to be continued till all the crevices between stones are filled and there is no movement in the stone. For quality assurance purposes hand broken stone should have Los Angeles Abrasion value not more than 40, sulphate soundness not more than 12 while any sand can be used provided its fineness modulus is not less 0.80 and its sand equivalent is not less than 50. No other test shall be required except that its in situ CBR shall not be less than 100 and its compaction shall not be less than 100% of the Laboratory Density. Such a sub base shall be highly drainable, would resist salt and capillary rise and would be not only resistant to deformation but would have a minimum layer coefficient value of 0.14 without any fear of drop of its value in sultry summers.

The learned AASHO Design Committee assigned a reduced value of 0.11 to sandy gravel and reduced value of 0.14 to crushed lime stone by increasing the structural value of asphalt concrete to 0.44. When ambient temperature does not exceed 20°C, asphalt concrete is bound to behave well. At high temperature, however, its layer coefficient value drops and as such for the same structural number the value of layer coefficient of sub-base and base must increase. Primary reason for the increase in the value of layer coefficient is the element of interlocking which hand breaking generates. Sand filled macadam is both drainable and interlocked and ipso facto its value can safely be taken as 0.14.

Water Bound Macadam

Water bound macadam which is not the macadam which John Macadam used for road construction purposes for the 1st time in the early nineteenth century. It is a highly improved altogether new material which suits us because of our peculiar requirements of weather, manpower, indigenous machinery and predominance of heavier axle loads. Water Bound macadam was in great use in both parts of Punjab in the pre and post partition era and its post-construction performance was more than satisfactory and far better than the roads being built as per the so-called latest state of art.

There is not much difference in the sand filled macadam and water bound macadam except that the fines in case of water bound macadam shall be calcareous rock dust and shall be spread dry over slightly rolled 3 ½" and down hand broken water borne river-run and nullah-run boulders with all-faces preferably broken. Dry stone dust shall be evenly spread and rolling shall continue till all the rock dust goes into the broken stone interstices completely without any signs of emptiness of interstices and movement of stone. When this stage is reached more stone dust shall be spread and rolling shall continue with enough spraying of water to make the

rock dust into a slurry which could thoroughly fill the interstices to the entire capacity of the inter-particle space.

During all this process of rolling, laying and spreading of stone and stone dust levels of grade and profile shall be checked by means of strength edges, pre-laid or placed control points of pegs or bricks established by means of leveling instruments and other construction gadgets so that finished base level shall have no more variation from design profile except what is permissible.

Hand broken stone shall have all sides broken with maximum size not exceeding 3 ½" and minimum 2 ½" having Los Angeles abrasion not more than 30 and sulphate soundness not more than 10. Rock dust shall be 100% calcareous stone dust having at least 95% Calcium / Magnesium Carbonate obtained from hard stone with 100% passing sieve No. 10 and not more than 3% passing sieve No. 200. In situ CBR in all cases must be more than 120 and compaction not less than 100% of Lab Density. In order to avoid formation of mini hogs and sags which traffic tends to produce, regular traffic shall not be allowed on water bound macadam. However, riding quality shall be checked by driving over it a light vehicle or car and correcting any bump if tangible or noticeable.

No gradation test is to be performed on sand filled macadam and water bound macadam. However before application of surface treatment a vehicle with heaviest possible axle load plying in Pakistan of 25 Ton or more shall be moved over the prepared surface to test the maximum deflection which should not exceed 0.1 mm.

In case deflection exceeds the permissible limit, thickness of the water bound macadam shall be suitably increased if it is not to be overlaid with semi-grout penetration otherwise, this test shall be repeated over the semi-grout penetration as elaborated in what follows.

Semi-Grout Penetration Macadam

If the design structural number as determined by AASHTO Pavement Design 1982 is not covered by the thickness of sand filled macadam as sub-base with layer coefficient as 0.14 and thickness of water bound macadam as base with layer coefficient as 0.20, semi grouted penetration macadam of adequate thickness shall be laid over water bound macadam taking its layer coefficient as 0.24.

Semi grout penetration macadam shall comprise of river-run or nullah-run hand broken stone with all sides broken and of the same quality and specifications as detailed in case of water bound macadam. It will be rolled and compacted with dry rock dust so that one third of the depth of the stone metal gets filled up with rock dust and the stone metal completely interlocked so that there is no movement under rolling or under traffic. When this stage is reached120 / 150 penetration grade bitumen shall be sprayed over the tested surface (tested both in respect of riding quality as well as compaction) at the rate of 75 lbs per hundred square feet. As much of this bitumen shall be filled into the crevices between the stone metal as possible by means of kerosene dipped synthetic brushes. Dry rock dust shall be spread over the penetrated bitumen / compacted surface at the rate of half cubic foot per hundred square feet of the prepared area and shall be evenly spread. Bitumen filling shall be taken up at least about 72 hours before multiple surface treatment commences so that bitumen in the crevices may get cured.

Multiple Surface Treatment

Talking of surface treatment is like going backward so far as the technical advancements in highway construction are concerned and similar is the case when we talk of water bound macadam and for that matter semi-grout penetration.

So far as riding quality is concerned no other highway material can match asphalt concrete. This is the only plus point the asphalt concrete has. The negative points are that it is too expensive, demands large fleet of imported machinery and plant to manufacture and lay. Moreover it ruts and settles down under the heavy axle wheels invariably during our hot summers. Yet another negative points is that bitumen in asphalt concrete as a result of weathering and oxidation cracks, revels and shoves in about a period of ten years.

So far as those countries are concerned who have cold climate and can afford to provide overlays after ten years or can mill the ruttings, it might be the only choice left. For us Pakistanis who build roads from borrowed moneys from loans, it would be impossible to provide timely overlays after expensive milling without borrowing further money. I do not know how we shall be able to overthrow the yoke of DAEWOO Loan when after so many years not a single penny has been paid towards the discharge of the loan. I am told that so far nothing has been paid from the collection of toll earning of M2 and the same can be expected to happen on the completion of M1. This is the sequel to building highly unfeasible roads to the great detriment of the national economy.

In the above milieu, there does not seem to be any wisdom or far-sightedness to continue to sink the economy of our motherland into more and more irretrievable loans in the name of progress or for the sake of riding pleasure which has nothing to do with the majority of our people who cannot dream of even buying a car.

This is our country. This is our land. When shall we own it as our own and rise above paltry wishes and pleasures and false considerations of pseudo progress which serve the people of pelf and privilege only.

The basic function of a road is to provide a safe and smooth movement of traffic at reasonable speed. Asphalt concrete roads are loved by road users for bump-free acceleration to speeds exceeding 100 Km / hr and going beyond 120 Km / hr. There is no justification of building roads of 4.5 PSR or IRI 2 when we can have surface treated roads at rock-bottom cost with PSR exceeding 3.75 depending upon workmanship and quality of construction.

It is highly fallacious and incorrect to say that asphalt concrete roads cover their cost in two years as a result of saving in operating cost as compared to surface treated roads. This fallacy is being propagated on the basis of extra smoothness required in the west because of predominance of car traffic as indicated by such World Bank supported gadgets as international roughness indicators. We should make use of the concept of present serviceability rating as introduced by AASHTO. Before acceptance of IRI version of roughness of our roads we should have its thorough calibration with what is acceptable riding quality and what is not on the basis of observation of panel of road users.

At this juncture of the talk, it would be appropriate to highlight the specific points, which establish edge of surface treatment over asphalt concrete especially in the present milieu of Pakistan.

Surface Treatment's Edge Over Asphalt Concrete

In spite of pejoration of surface treatment by all and sundry, it has edge over asphalt concrete in our environs in so many ways :

- The most significant point in favour of surface treatment is that it is indigenous. It can be carried out with local expertise and local labour and for the purpose of improvement of its riding quality comparable to asphalt concrete, local people can easily be trained and educated and PSR approaching 4 can be achieved most cost-effectively.

- No imported machinery is required. For popularizing surface treatment indigenous machinery can be manufactured in Pakistan. This would boost up and give impetus to development of local industry.
- Surface treatment is the only method of construction, which can give non-skid surface not only to surface treatment itself but also extra-smooth skid-prone asphalt roads. This aspect is very important for road safety and for avoiding and minimizing road accidents.
- If compaction of sub-grade, sub-base and aggregate base is guaranteed, rutting can totally be eliminated with surface treatments. There is no room for any settlement under the wheels in surface treatment if there is no settlement in base, sub-base or sub-grade because of stone to stone contact with minimal of bitumen – a construction stage which cannot easily be obtained in case of asphalt concrete.
- One of the major factors in surface treatment is that it is labour-oriented and requires very little machinery except for rolling and spreading of aggregate. Aggregate can be spread very effectively manually and chip-spreader can be dispensed with. If aggregate spreading is insisted upon through machinery, chip spreader can easily be manufactured within the country.
- Another point where surface treatment has an edge over asphalt concrete is that it is highly cost effective both when used for wearing course or for resurfacing or rejuvenating old cracked asphalt or surface treated surfaces. It is for this reason one of the biggest factor as it makes surface treatment most affordable as compared to the expensive overlays. Keeping in view the present day market rates the per inch and per square foot cost of routine triple surface treatment in Islamabad is Rs. 7/- while that of asphalt concrete is Rs. 14/-. For economy-conscious country like Pakistan this single parameter is enough to go for surface treatment.
- There is nothing in surface treatment, which calls for any foreign exchange. The aggregate is local, the bitumen is local and all the machinery needed in surface treatment is local what to speak of the local labour and expertise.
- Technically the best aggregate for surface treatment is natural river or nullah-run water-borne rounded aggregate which does not require any crushing except manual screening. Thus when we shift to surface treatment we not only save electricity for utilizing in essential industries we also create screening jobs for labour. Rounded aggregate can not be used in asphalt concrete as it would drastically drop its stability and would give impetus to quick rutting.
- Surface treatment is easy to maintain as compared to asphalt roads. Its maintenance is both cost-effective and easy and requires very little machinery as compared to maintenance of asphalt concrete. Surface treated roads develop cracks in a period of about ten years because of weathering and oxidation. These cracks can easily be taken care of by provision of a single coat of surface treatment which will cost only Rs. 3/- per square foot as compared to Rs. 14/- in case of asphalt concrete overlays. Thus the maintenance cost of surface treatment would be hardly one fifth of overlay cost. Does it not suit us ?
- Riding quality of surface treatment can be made quite comparable to asphalt concrete by provision of a smoothening coat of coarse sand and taking extra care in checking the unevenness in the aggregate base below before taking up the surface treatment. Smoothening coat shall not cost more than re. 1.5/- per square foot.

- Keeping in view the demands and exigencies of traffic surface treatment can be of as many coats as would suffice the traffic needs as explained and demonstrated in the following pages. Surface treatment can be single, double or triple coat and if need be of as many coats has five, six or seven and so on according to the requirements in each case. Thus it can totally replace asphalt concrete.

- If water bound macadam is used in preference to present day aggregate base and sub-base, bitumen of the first coat would get partly penetrated into the water bound macadam giving it monolithicity and greater structural strength for better performance of the end product.

- There is no possibility of development of rutting in surface treatment as well as water bound macadam and sand filled macadam because of great resistance of water bound and sand filled macadam to displacement and development of potholes. For this reason if sand filled and water bound macadam are adopted in preference to what is being provided today, there shall be no need to impose embargo on the plying of heavier axle loads. Because of adequate thickness of sand filled and water bound macadam the pavement structure would be too strong to require any false prop of embargo on heavier axles which neither suits our economy nor the transporters.

- As explained earlier matchable wearing surface like that of asphalt concrete is possible with surface treatment with sand seal at a paltry additional cost.

- Multiple surface treatment is the only choice left with us if we want to avoid rutting, if we want to avoid rutting, if we want to economize and if we want to build strong enough roads to resist rutting in all eventualities which asphalt roads can never do.

- As compared to the developing countries, the developed countries are the major consumers of petroleum, which gives rise to large bulk of bitumen as a bye product, which is to be consumed in any way. It was for this reason necessary for countries like America to establish asphalt institutes and TRRL like laboratories, which could promote the use of bitumen as the primary ingredient for road construction. Use of full depth asphalt concrete is one such attempt where the institute has devised technical justification for maximizing to use of bitumen. To me giving highest structural values to asphalt concrete on the basis of AASHTO Road Test was the premier endeavour in this direction. Europeans and Americans, therefore, do not champion and support surface treatment as a continuation of their policy to stress the maximum use of bitumen as an integral part of their political foresight which initially triggered the establishment of Asphalt Institute as a result of car boom in America in the start of 20th century. Are we not becoming a part of their calculated policy by perpetuating the use of asphalt concrete ?

- Another reason that the westerns do no support the use of surface treatment is the type of surface treatment we can do in Pakistan making the most of our torrid and hot summers. This quality of surface treatment is not possible for the Americans and the Europeans to achieve because of their cold climate where asphalt concrete can perform much better than in our case. We should have the ken to see what is good for us and what is good for them.

- European and the Americans are pedagogues and respected teachers of majority of our consultants and Engineers in senior positions. They hold degrees from their institutions. It is but natural for them to respect the opinions of their learned teachers and disparage and belittle surface treatment as an inferior material and third grade choice.

- The biggest manufacturers of construction machinery and especially asphalt concrete machinery are the Americans and the Europeans. It would go against their interest if they champion or support any material or method of construction where the use of their machinery may get jeopardized or minimized. This is again one of the reasons that surface treatment is not supported by all those who are one way or other connected with the manufacture of machinery. This is too big and too powerful a cartel to be gone against by developing countries because most of the loans are usually tied up with import of machinery from a particular country. Surface treatment is the only means of steering clear of these cartels, creating opportunities for the developments of our own machinery and reducing demand of foreign exchange so necessary for strengthening our economy.
- If we shift from asphalt concrete to surface treatment we shall be able to avoid loans, foreign technical assistance as well as expatriate consultants at least in road construction. This again would be highly salutary for our economy.
- Surface treatment can open new vistas of rapid development without begging any loans and without putting our dependence on them.

We are prevented from the use of surface treatment by pseudo-experts on the plea that surface treatment cannot give good riding quality and its IRI on initial construction would never be less than 8.

- Surface treatment has no structural contribution.
- There is no documentation of its past performance.

These are all untenable, preposterous and implausible charades, which have been spread purposely as elaborated in depth above.

In present environs when the art of surface treatment is on verge of extinction because of predominance of hot-laid hot rolled bituminous concrete it is vitally important to comprehensively and exhaustively highlight the concept of surface treatment for the benefit of those engineers who for one reason or other are not familiar whit it.

It is necessary to point out that the culture of carrying out proper and quality surface treatment has almost died. It needs to be revived by creating demand for hand broken stone and one-sized water-borne rounded bajri or one-sized cubical shaped crushed quality stone for all the coats required to be carried out. It is also necessary that highway laboratories and institutions should impart training for surface treatment.

The Vanishing Art of Surface Treatment

With the virtual termination of such like old timers as Road Inspectors, Road Mates and Road Gangs, the art of surface treatment is almost on the verge of extinction. What we see on tertiary and secondary provincial and district roads is not the surface treatment it used to be. Surface treatment culture is gradually vanishing as the demand for this mode of provision of wearing surface is diminishing since the large scale induction of asphalt concrete after eighties.

A few decades back the only means of provision of wearing surface for all type of roads was surface treatment. Except for the process of rolling construction of roads was all manual including surface treatment itself. Aggregates for surface treatment was single size water-borne bajri abundantly available in our up-country rivers and nullahs. Single size water-borne bajri was screened, collected and stockpiled on various locations of Grand Trunk Road. The most famous were Burhan, Bhimber, Havelian, Sakhi Sarwar and Sargodha in Punjab and similar strategic locations in others provinces.

For quality construction of surface treatment, there is no room for any gradation in any coat since a uniform layer of equal thickness can only be laid if the aggregate is of one size. In one layer if aggregate is graded or of different size in same coat, it will be impossible to have smooth ride. This is one of the primary reasons that the present day surface treatment where care is not being exercised and graded aggregate is being used is not giving the riding quality it should give.

It is therefore necessary that half inch thick aggregate must be half inch so that each aggregate may hug the next and may get firmly seated into the bitumen below over an almost equal area with equal adhesion and equal resistance to displacement under the traffic wheel.

Europeans and the American do not give due importance to surface treatment and mentally accept its riding quality as inherently poor and that is why material of each coat is specified as graded by such seasoned and lofty American Institutions as Federal Highway Administration. Ours, however, is altogether a different case. If we adopt surface treatment as replacement to asphalt concrete, it must be quality surface treatment and each coat must have aggregate of one size as explained above.

Principles of Surface Treatment

If acceptable and sustainable riding quality is to be achieved, bajri or stone aggregate of each coat of surface treatment must be of one size with zero variation as far as possible. The rate of spread of aggregate in a given area in each coat depends upon its size, while rate of spread of bitumen is also linked with the size of the aggregate and its volume to be spread. For each size of aggregate both the quantity of bitumen and aggregate stands determined and finally considered reasonable in view of the past experience of 10 decades in the pre partition and post partition era. It is the state of art of surface treatment developed by quality conscious and seasoned engineers of Indo-Pakistan.

The quantity of aggregate to be spread in each coat can be worked out by multiplying the area with the proposed thickness. The quantum of aggregates thus worked out shall be the quantity of bajri laid horizontally in a very tight position without any inter-particle gap which is not possible to be achieved when spread through labour or chip spreader. It has been observed on the basis of long experience of construction that not more than 65% to 70% of the calculated quantity gets spread. Accordingly this much quantity is fixed for spreading in each coat for each size and the amount of bitumen to be spread is worked out by multiplying the cubic contents of the quantity of the aggregates with 6 to 10. This is because of the number of layers involved, ambient temperature of resurfacing and position of coat to be laid as well as mature, diversity and density of traffic expected to ply on the road. When the quantity of aggregates shall be in cubic feet per % square foot, the resultant of multiple of 6 to 10 shall bitumen in lbs per % square foot, of the surface covered. Normally minimum rate of spread in 2nd coat and above should not be less than 14 lbs per hundred square feet and 8 lbs in the final coat and almost the same quantity of bitumen in the smoothening coat.

During first year after construction surface treatment is highly non-skid and its IRI may give false indication of its riding since after one or two exposures of heat of June and plying of traffic, bitumen gets worked-up and a perfectly sealed surface is revealed with much better riding quality. However initial year's riding can greatly be improved by providing a smoothening coat of sand seal over final coat of surface treatment. With smoothening coat riding quality of surface treatment will become comparable to asphalt concrete and the myth that asphalt concrete covers its cost in saving in operating cost in two years as compared to triple surface treatment would get fully exposed.

In surface treatment, multiple surface treatment has great potential to completely replace asphalt concrete at less than half the cost. It has the in-built and inherent economic benefits of providing employment to thousand of workers, reduction in electric consumption, reduction in import of construction machinery and spare parts. Moreover, it will give boost and

incentive to local manufactures of indigenous machinery and will give rise to substantial saving in foreign exchange to the great chagrin of the loan-giver who do not want the developing countries to escape from their ever-tightening tentacles.

Surface treatment has not only large potential but also a wide spectrum of applications. Surface treatment could be single coat, double coat or triple coat or as many coats excluding the smoothening coat as necessary to meet the specific traffic and loading requirements. A large variety of surface treatment application paradigms is given below as a guide line in accordance with the basic principles of surface treatment and empiricism of 10 decades.

River-run round gravel should always be preferred over crushed aggregate because of its superiority in offering resistance to wear, impact and weathering as well as its ability to offer least resistance to movement of wheel.

Surface treatment should not be carried out when the ambient temperature is less than 30°C but preferably more or when the aggregate is highly dusty or when there is excessive humidity or during and immediately after rains. This will be so because excessive dust will act as barrier between the bitumen and the aggregate and the aggregates are likely to strip, revel or shove under the traffic. When the aggregate is wet or humid, water would play the similar role of a barrier between the bitumen and the stone and this would ultimately tell upon the performance of surface treatment.

In cold countries there is very little possibility of the success of the type and quality of surface treatment I am talking about. In temperate and cold climates the type of surface treatment which can match in performance to asphalt concrete cannot be carried out nor is possible to be carried out because it is only rare when ambient temperature in those countries is above 30°C. In cold climates surface treatment is carried out with cold emulsion which is too weak to bear the brunt of heavy traffic and is no match to hot weather surface treatment.

SURFACE TREATMENT APPLICATION PARADIGMS

The following are the various application paradigms of surface treatment, which can be made use of for a host of construction variations and situations as per the exigencies of execution. We shall start from typical single coats to double coats and then from application on tertiary roads to primary roads including national highways and those roads where extra heavy treatments are called for. The quantity of bitumen and the rate of spread of aggregate specifically pertains to the exact size of the aggregate mentioned here below. In case the size is even slightly reduced the quantity of bitumen and aggregate will have to be reduced accordingly otherwise the surface treatment may bleed.

In the following tables SCA-8 means Single Coat Application No. 8, DCA-5 means Double Coat Application No. 5, TCA-3 means Three Coat Application No. 3 and MCA-7 means Multiple Coat Application No. 7.

Single Coat Applications

The various applications of surface treatment are as under :

Table No.	Aggregate Per Hundred Square Feet		Bitumen Per Hundred Square Feet
	Size	Qty.	
SCA-1	Coarse Sand	½ Cft.	5 Lbs.
SCA-2	1/8"	¾ Cft.	8 Lbs.
SCA-3	¼"	1 ½ Cft.	14 Lbs.
SCA-4	3/8"	2 Cft.	18 Lbs.
SCA-5	½"	2 ½ Cft.	22 Lbs.
SCA-6	¾"	4 Cft.	35 Lbs.
SCA-7	1"	5 ½ Cft.	45 Lbs.
SCA-8	1 ½"	8 Cft.	60 Lbs.
SCA-9	2"	11 Cft.	75 Lbs.

Double Coat Applications

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-1	Size	Qty.	
	¼"	1 ½ Cft.	14 Lbs.
	1/8"	¾ Cft.	8 Lbs.
		2 ¼ Cft.	22 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-2	Size	Qty.	
	3/8"	2 Cft.	18 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
		3 ½ Cft.	32 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-3	Size	Qty.	
	3/8"	2 Cft.	18 Lbs.
	1/8"	¾ Cft.	8 Lbs.
		2 ¾ Cft.	26 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-4	Size	Qty.	
	½"	2 ½ Cft.	22 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
		4 Cft.	36 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-5	Size	Qty.	
	½"	2 ½ Cft.	22 Lbs.
	1/8"	¾ Cft.	8 Lbs.
		3 ¼ Cft.	30 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-6	Size	Qty.	
	½"	2 ½ Cft.	22 Lbs.
	3/8"	2 Cft.	18 Lbs.
		4 ½ Cft.	40 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-7	Size	Qty.	
	¾"	4 Cft.	35 Lbs.
	3/8"	2 Cft.	18 Lbs.
		6 Cft.	53 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-8	Size	Qty.	
	¾"	4 Cft.	35 Lbs.
	½"	2 ½ Cft.	22 Lbs.
		6 ½ Cft.	57 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-9	Size	Qty.	
	1"	5 ½ Cft.	43 Lbs.
	½"	2 ½ Cft.	22 Lbs.
		8 Cft.	65 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-10	Size	Qty.	
	1"	5 ½ Cft.	43 Lbs.
	3/8"	2 Cft.	18 Lbs.
		7 ½ Cft.	61 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-11	Size	Qty.	
	1 ½"	8 Cft.	56 Lbs.
	¾"	4 Cft.	28 Lbs.
		12 Cft.	84 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-12	Size	Qty.	
	1 ½"	8 Cft.	56 Lbs.
	½"	2 ½ Cft.	22 Lbs.
		10 ½ Cft.	78 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-13	Size	Qty.	
	2"	11 Cft.	77 Lbs.
	1"	5 ½ Cft.	38 Lbs.
		16 ½ Cft.	115 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
DCA-14	Size	Qty.	
	2"	11 Cft.	77 Lbs.
	¾"	4 Cft.	28 Lbs.
		15 Cft.	105 Lbs.

The riding quality of double surface treatment of two coat work will be highly non-skid and rough to drive at with micro-hogs and micro-sags which shall need to be smoothened with fine coats of 1/8" and sand seal. Even if the finished levels of water-bound macadam are within AASHTO tolerance limits, the smoothening role of premixed sand seal is too vitally important to be ignored. In case of surface treatment the space between the two stone particles of a given coat is invariably lower than the general spread line of the stone aggregates. This gives rise to a chain of micro-depressions which produces a typical sound when traffic tires move over it. Road Users especially car-owners do not like this sound as it appears to affect smooth ride of their car. Sand having fineness modulus of at least 1.5% when mixed with 7% to 8%, 80 / 100 bitumen can be evenly spread over the surface treatment to fill the mini-depressions with especially designed wooden trowels. This when rolled with light tandem roller will give a very smooth surface with excellent riding quality comparable with any asphalt concrete wearing course surface. It would, however, demand careful driving in rains, as it would be skid-prone.

It may, however be mentioned that in the above tables the quantity in two coat work stands strategically reduced in certain applications to avoid contractors playing with.

Three Coat Applications

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-1	Size	Qty.	
	½"	2 ½ Cft.	22 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
	1/8"	¾ Cft.	8 Lbs.
		4 ¾ Cft.	44 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-2	Size	Qty.	
	¾"	4 Cft.	35 Lbs.
	3/8"	2 Cft.	18 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
		7 ½ Cft.	67 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-3	Size	Qty.	
	¾"	4 Cft.	35 Lbs.
	3/8"	2 Cft.	18 Lbs.
	1/8"	¾ Cft.	8 Lbs.
		6 ¾ Cft.	61 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-4	Size	Qty.	
	1"	5 ½ Cft.	38 Lbs.
	½"	2 ½ Cft.	20 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
		9 ½ Cft.	72 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-5	Size	Qty.	
	1"	5 ½ Cft.	38 Lbs.
	3/8"	2 Cft.	18 Lbs.
	1/8"	¾ Cft.	8 Lbs.
		8 ½ Cft.	64 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-6	Size	Qty.	
	1 ½"	8 Cft.	64 Lbs.
	¾"	4 Cft.	30 Lbs.
	3/8"	2 Cft.	18 Lbs.
		14 Cft.	112 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-7	Size	Qty.	
	1 ½"	8 Cft.	64 Lbs.
	½"	2 ½ Cft.	23 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
		12 Cft.	101 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-8	Size	Qty.	
	2"	11 Cft.	77 Lbs.
	1"	5 ½ Cft.	38 Lbs.
	½"	2 ½ Cft.	20 Lbs.
		4 Cft.	135 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-9	Size	Qty.	
	2"	11 Cft.	77 Lbs.
	¾"	4 Cft.	28 Lbs.
	3/8"	2 Cft.	18 Lbs.
		4 Cft.	123 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
TCA-10	Size	Qty.	
	2"	11 Cft.	77 Lbs.
	¾"	4 Cft.	28 Lbs.
	¼"	16 ½ Cft.	14 Lbs.
		16 ½ Cft.	119 Lbs.

Mini-hogs and mini-sags will be more predominant in coarser three coat applications and there shall be all the more necessity to smoothen them and make them acceptable to road users by applying two additional coats. One coat of 1/8 " thick fine aggregate and another coat of coarse sand seal. A very important point to be kept in mind in the use of surface treatment is that for the sake of extra smooth riding quality matchable with asphalt concrete care needs to be taken that double particles of aggregate may not come over the previous layer during the course of laying of second coat.

Multiple Coat Applications

With multiple applications not only the thickness of surface treatment can be increased, its structural contribution can also be enhanced substantially. It would thus become indigenous asphalt concrete without any asphalt plant, without deployment of large fleet of asphalt machinery, without going into the intricacies of job mix formula and its approval and without any engagement of asphalt experts.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
MCA-1	Size	Qty.	
	2"	11 Cft.	77 Lbs.
	1"	5 ½ Cft.	38 Lbs.
	½"	2 ½ Cft.	22 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
	1/8"	¾ Cft.	8 Lbs.
	Coarse Sand	½ Cft.	5 Lbs.
		21 ¾ Cft.	164 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
MCA-2	Size	Qty.	
	1 ½"	8 Cft.	64 Lbs.
	¾"	4 Cft.	32 Lbs.
	3/8"	2 Cft.	18 Lbs.
	3/16"	1 Cft.	10 Lbs.
	Coarse Sand	½ Cft.	5 Lbs.
		15 ½ Cft.	129 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
MCA-3	Size	Qty.	
	1"	5 ½ Cft.	44 Lbs.
	½"	2 ½ Cft.	22 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
	1/8"	¾ Cft.	8 Lbs.
	Coarse Sand	½ Cft.	5 Lbs.
		10 ¾ Cft.	93 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
MCA-4	Size	Qty.	
	¾"	4 Cft.	35 Lbs.
	3/8"	2 Cft.	18 Lbs.
	3/16"	1 Cft.	10 Lbs.
	Coarse Sand	½ Cft.	5 Lbs.
		7 ½ Cft.	68 Lbs.

Table No.		Aggregate Per Hundred Square Feet	Bitumen Per Hundred Square Feet
MCA-5	Size	Qty.	
	½"	2 ½ Cft.	22 Lbs.
	¼"	1 ½ Cft.	14 Lbs.
	1/8"	¾ Cft.	8 Lbs.
	Sand	½ Cft.	5 Lbs.
		5 ¼ Cft.	49 Lbs.

In the presence of the above plethora of surface treatment paradigms we have large choice of application which completely renders asphalt concrete unnecessary especially when we know that we cannot prevent it from rutting, when it is highly expensive to construct and maintain and when neither any foreign know-how nor any expatriate expertise is needed.

At this juncture it will not be out of place to comment upon the decisions taken by the Chairman National Highway authority at the end of a seminar held in August 2003, relating to the use of 40 / 50-grade bitumen. The Chairman declared that NHA from henceforth would go for water bound macadam and 40 / 50-grade bitumen. The Chairman has admitted that the past performance of water bound macadam has been far better than that of aggregate base. The point to be noted here is that wherever there was water bound macadam, it was invariably overlaid with surface treatment. The performance of water bound macadam is in fact the performance of surface treatment.

I am pleading for water bound macadam since 1983-84. After twenty year, it has been conceded that my stance was correct. Availing of this opportunity I may point out that in the best interest of my country I am championing the case of surface treatment since the beginning of the last decade. That day is not far off when its superiority over asphalt concrete so far as the aspect of rutting is concerned, will be admitted by all. This is because it was I who as Project Manager Lahore Sahiwal Third Highway Project first pointed out that the Stability of asphalt concrete should be increased from then specified 700 Kg to 1000 Kg. At the time of giving of my suggestion the NBH did not readily agree because Mr. Ralph O Hill and Mr. Cairme opposed my suggestion. But after a few years NHB had to increase it to 1000 Kg when it came to light that lower stability tends to give rise to earlier rutting. 40 / 50-grade bitumen would definitely delay development of rutting but it cannot totally stop it. On other hand it will reduce durability and increase maintenance cost because of earlier development of reveling, separation of bitumen from the aggregates and consequent disintegration of road pavement simply because it will gradually get transformed into 30 / 40, then 20 / 30 and then still more harder with the passage of time.

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25 YEARS OF EXCELLENCE

National Development Consultants

1977-2002

KEY DATA

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Registered with Pakistan Engineering Council since 31 December 1977 under Serial No. CONSULT-71
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OWNERSHIP
Partnership

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Civil Engineers	185
Agricultural Engineers /Agronomist	16
Electrical and Mechanical Engineers	7
Allied Professional (Economist, Sociologists, Soil Scientists)	42
Hydrologists, Geologist ,Hydro-geologists	16

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MAJOR ON-GOING PROJECTS

- Chashma Right Bank Irrigation Project Stage-III Client: WAPDA
- Pehur High Level Canal Project Client: Government of NWFP.
- Fordwah Eastern Sadiqia South Project Client: WAPDA
- Post Flood Rehabilitation and Protection Project Client: Government of Pakistan
- IIIrd Punjab On-Farm Water Management Project Client: Government of the Punjab
- Punjab Private Sector Groundwater Development Project Client: Government of the Punjab
- Remodelling Thal Canal Project Client: Government of the Punjab
- National Drainage Programme Client: WAPDA
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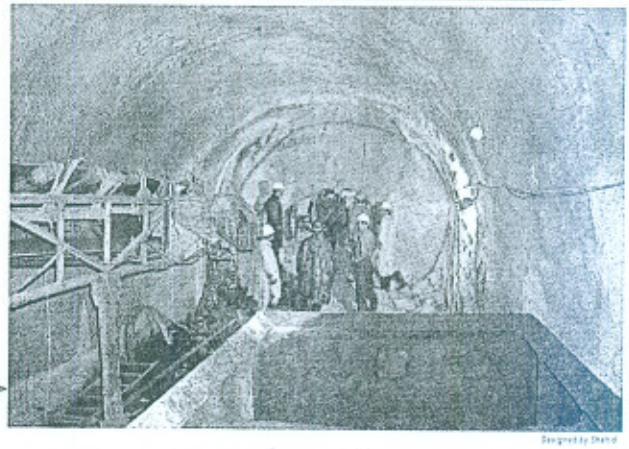

Designed by Shahid