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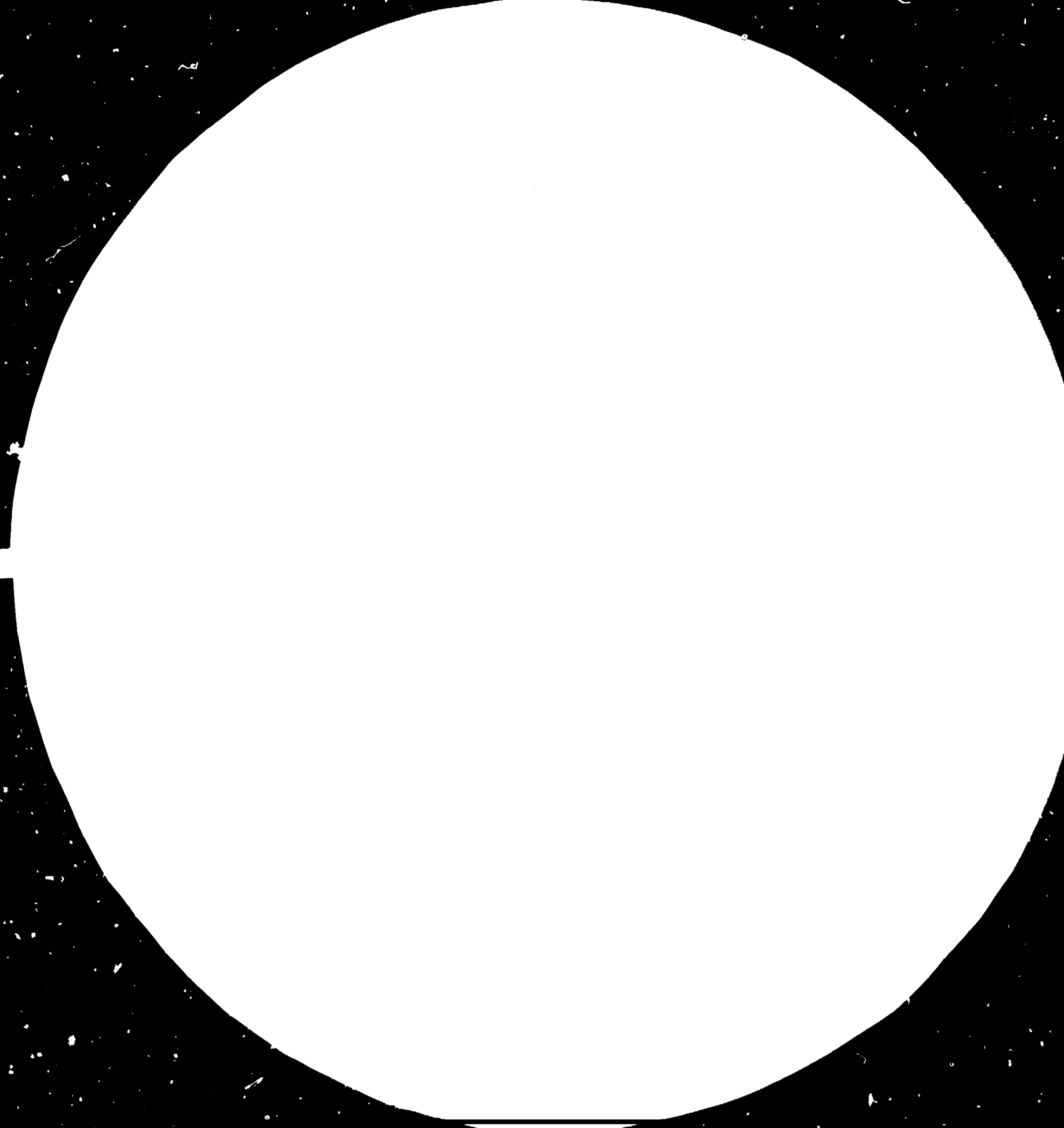
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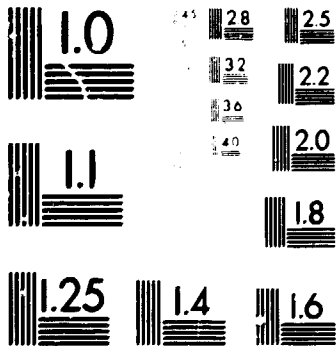
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DP/ID/SER.A/488
21 December 1983
English

RESEARCH AND DEVELOPMENT
FOR FLY ASH UTILIZATION
DP/CPR/81/026
PEOPLES'S REPUBLIC OF CHINA .

Technical Report*
Basic Properties of Concrete Admixed
with Fly Ash .

Prepared for the Government of People's Republic of China
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Philip L. Owens
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Vienna

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Introduction

This report outlines the activities in the form of visits, a programme of lectures, discussions and observations when on assignment to the Shanghai Building Science Research Institute. The mission occurred during the period October 22 to November 14 inclusive, to fulfill the requirements of U.N.I.D.O. mission Index No. E555049, 83-354 on the utilization of fly ash, a waste material from coal burning electric generation power stations. The mission also included briefing and debriefing at the U.N.I.D.O. office in Beijing.

The Assignment

The mission could be described as a three part task as follows :

- i) Investigatory visits, to become acquainted with the normal conditions that operate in construction materials and practices, particularly as they apply to concrete construction in the area of Shanghai. In general the objective was fulfilled, but as would be expected, communication in specific areas of importance could not always be appreciated. For instance, the most popular cement used in Shanghai is composed of a mixture of about 53% Portland cement clinker and gypsum, 35% granulated blast furnace slag and 12% fly ash. The cement works visited was not intergrinding either slag or fly ash; the facilities were there but not in operation. Also, fine aggregates for concrete are imported, thus it would be advantageous to use fly ash to replace not only part of the cement, but also some fine aggregate.
Details of the visits are given in Appendix 1.
- ii) Programme of 10 lectures. These took place from Monday October 31 to Thursday November 10 inclusive, with a rest day on Sunday November 6. The programme was first discussed in detail on October 24 and summaries of the lectures in the required format by October 25 to enable translation. Each lecture was accompanied by slides and prepared overhead projection illustration. An outline of the lecture was prepared and given to the interpreter before delivery of each lecture and, to aid the understanding, this summary in English was projected on the overhead screen as the lecture progressed. The normal length of lecture was about 2 hours, which included a 15-minute break. The audience was generally of 80 to 110 people, the majority

understanding English, and ranged from Professors to technicians. The list of participants and numbers attending each lecture have been recorded by the Shanghai Building Science Research Institute. Mme. Jai has the details, but there were participants from 14 Provinces. The lectures were recorded and copies of the slides and overhead material were taken.

The process of preparation and delivery was at times very exhausting as, on many occasions, it was not before 22.00 hrs. that the next day's lecture had been prepared in detail. The continuity and often the basic information required in the preparation could not be completed because of the lack of reference material. It was with regret that some 10kg of reference material had to be shed before leaving U.K. to comply with the 30kg limit for travelling. The lectures, except one, were given in the early morning; the details are in Appendix 2.

iii) Discussions. These took two forms, the first as extensions to the lectures and lasted for the minimum of one hour to more than two hours. However, the hosts were concerned to keep the discussion periods as short as possible during the period of the lectures. The interest, however, often caused the discussion periods to be prolonged, especially those that took place in the afternoons. The discussions were generally on the basis of written questions; the details are in Appendix 3.

The second series of discussions were with the Shanghai Building Science Research Institute and ranged over the full scope of fly ash utilization, as it would be practiced in Shanghai. The topics discussed are given in Appendix 4.

While the general use of fly ash in concrete was discussed in depth to understand and optimize the present conditions, there is no doubt that, should the demand for electricity ever approach a satisfactory level, the amount of coal ash produced would pose a serious problem to the environment, local to the power plant. This, together with cooling water and combustion gas emissions, needs careful consideration now as there is sufficient time. A comprehensive approach to the problem was proposed as a method of utilizing and optimizing power station by-products. The details of the suggestion are given in Appendix 5.

Observations and Comments

A significant aspect of this type of assignment, where the hosts are anxious and capable of fulfilling the objectives and are striving hard to understand the principles, makes for very hard work, especially if they are stimulated and interested. Presenting ten lectures in such rapid succession, with much of the in-depth background information and important reference material that would, under normal circumstances, have been to hand, was not conducive to a relaxed lecturing style because of the problems with lecture preparation.

Nevertheless, the lectures appeared to have been well received as they stimulated enthusiasm for new approaches to the methods of analysis and preparation of experimental work with concrete. But, as my experience and qualifications are limited to those of an industrial concrete technologist in the application of concrete materials, the in-depth knowledge on fundamental research techniques was therefore lacking. There is no doubt that China is about to become a prominent industrialized nation and that it is the shortage of electrical generation that is preventing and retarding industrial expansion. This, coupled with the need to use the coal resources as the principle form of energy, could create serious environmental problems, if the decisions on fly ash utilization are delayed through either lack of appreciation of the problem or funding at the time the power plant is planned or even under construction. An added complication is that the coal resources presently used normally contain more than 22% ash which, when compared with either U.K. coals with about 17% and Australian at less than 10%, presents a significantly greater challenge to the resourcefulness and determination to solve the problem of environmental pollution and land dereliction.

It is also evident that the Shanghai area is short of the normal resources of aggregates in the form of sand and gravels, but as the greatest single conurbation in China, the need to refurbish industry and rehouse the present population is a major priority and every means possible to supplement the primary resources is vital. The problem with fly ash is that in a finely divided form its use is limited as an admixture to concrete, to 10 or 15% of the mass of concrete. Thus, it is necessary to give consideration to the processes that produce aggregates from fly ash. The Shanghai Building Science Research Institute appreciate the scope of the problem and of the urgent need to convince their construction industry

of the valid uses for fly ash. They have many established uses for fly ash now, but they have their limitations because of the requirement for capital investment. Thus, uses where low or no capital is required are very attractive. This is at the very centre of the dilemma and there is an urgent need for the developed countries to provide experience and data on the longer term performance of concrete containing fly ash, particularly in reinforced and prestressed construction. The Institute are enthusiastic and with a relatively small amount of funding and technical aid, are capable of doing their own research, given sufficient time, which they might not have. Nevertheless, in the process it is inevitable that they will establish a reputation for one of the world's foremost authorities, not only in the science of fly ash utilization, but also more importantly they will be able to give adequate technical support on the uses of fly ash to the construction industry of China.

Conclusions

1. The type of fly ash produced in the Shanghai area is from bituminous coals which have a minimum of 22% ash content. This does not, or should not presuppose, that all coal in China is of this type or quality. It is anticipated that the full range of solid fuels exist from anthracite to peat, which are all used in power stations throughout the world.
2. The fly ash produced in Shanghai, when used in conventional concrete, has a slightly lower reactivity (strength development) than U.K. fly ashes of comparable grade. This is possibly due to the lower Potassium and Sodium Oxide levels.
3. The fly ash produced follows the general rule that, as the percentage on the 45 μ m sieve residue reduces, the water requirement reduces at any fixed amount of cement replacement. Thus, if the fly ash is of a generally high sieve residue, then water reduction has to be induced by other means, i.e. water reducing admixtures.

It is very important that fly ash concrete should have a lower water requirement than concrete made with Portland cement alone. This is in order to promote reaction between the products of cement hydration by concentrating the pore solutions.

4. The amount of fly ash used in structural concrete can be increased as the fly ash becomes coarser, replacing not only a proportion of the cement, but also the fine aggregate. Typically, the amount of fly ash can be increased from, say 100 kg/m^3 of fine grade fly ash to more than 250 kg/m^3 of coarse ash, but the influence on the properties of concrete have to be more thoroughly investigated, especially the effect on water requirement.
5. Laboratory tests at 20°C can, and do, give results which indicate poor performance at early ages when compared with Portland cement concrete. In the evaluation of higher fly ash content concrete tests designed to relate closer to the conditions in practice are necessary. It is also important to pay particular attention to the freshness of samples and the preparation of materials so that they perform in a similar manner to that in practice.
6. When considering the clauses for a local specification for fly ash, attention should be particularly paid to the quality of the fly ash, irrespective of grade, with the intention of reducing variability, i.e. $45 \mu\text{m}$ sieve residue should have both minimum and maximum levels.
7. The long term performance of high fly ash concrete can be anticipated by the examination of aged insitu concrete made with Portland blast furnace cement, i.e. cements containing up to 85% granulated blast furnace slag, of which there is considerable long term experience in Shanghai. The reason is that the gel structure of the two systems, i.e. concrete made with either slag or fly ash, have similar permeability characteristics to both water and gas.
8. The application of rapid test techniques in laboratories sited in critical positions in any process involving fly ash, so that decisions can be made with sufficient speed to optimise the grades and quality of fly ash to avoid processing whenever possible.

Recommendations

For the conditions that at present exist in Shanghai -

1. To optimise the amount of fly ash utilization in all grades of concrete, plain and reinforced, etc., the specification should include its use as part of both the cement content and the fine aggregate.
2. For these conditions the quality, i.e. variability, of the fly ash should be low, but it is not necessary to have a grade of fly ash with a low 45 μ m sieve residue. The sieve residue can therefore be any value that can be maintained within say \pm 5% of that value.
3. If the 45 μ m sieve residue has a mean value that exceeds 15%, then it is very important to reduce the water content of the concrete by other means, i.e. the use of a water reducing admixture.
4. To evaluate the limits of the grade of fly ash to be specified, tests should include the performance of concrete under conditions similar to those that occur in practice, as well as at 20°C.

For the conditions that may possibly exist in Shanghai in 5 to 10 years' time -

5. Because of the inevitable probability that the volume of fly ash will be increased by three or four times that presently produced, preparations should be made now to establish the various ranges of construction and other products that are possible by using fly ash as a basic raw material.
6. Whilst the outline proposal in Appendix 5 can be developed, it is necessary to make preparations so that the technology of the various techniques of manufacture and use are understood, before planning such a comprehensive approach to the problem.

APPENDIX 1

List of Technical Visits

25 October - a.m. : Toured the laboratories of the Shanghai Building Science Research Institute.

p.m. : Jing Shan Cement Works, about 50km from Shanghai. A single rotary kiln wet process, producing about 200,000 tonnes Portland clinker. At the time of visit no fly ash or slag were being used.

26 October - a.m. : i) Bao Shan Steel Complex to visit the ready mixed concrete plant of a type very popular in U.S.A. and western Europe 25 years ago. Very clean and well maintained.

ii) Construction site visit to strip mills under construction - pump concrete. Over site concrete used fly ash.

Noticed the public highway construction use of fly ash/lime/aggregate road base.

p.m. : i) Ming Hang Power Plant about 35km from Shanghai on Hnang Pu river. The plant had 4 x 125 MW boilers on pulverized coal. Other 6 small generators on oil. Coal quality about 22% ash.

ii) Ming Hang fly ash plant, nearing completion and commissioning. The air classifier was stripped down for adjustment.

27 October - a.m. : i) Wu Jing silica products works established 1960. Large block manufacture, 22 hour steam curing of lagoon fly ash, lime, gypsum clinker and lightweight aggregate for both panels and blocks. Panels were not in production. The complex also contained an autoclaved aerated block plant.

ii) Wu Jing Pipe Works. Mandrill pipes using fly ash appeared to be very dense and high quality.

27 October - p.m. : i) Shang Men Construction site, southern suburbs, using large blocks. The method of construction was very interesting and very efficient. Apparently, about one third of construction in Shanghai since the liberation has used this form of construction. The site was unusually tidy with very little debris.

ii) Construction site, northern suburbs, using the panel method of construction. Inspected the typical and basic two room accommodation, with southern aspect small balcony, toilet/washroom and kitchenette.

31 October - p.m. : Hung Jing No. 1 Precast Works in Shanghai district. Established in late 1960's. An interesting elevator style atmospheric steam curing of wetcast edged slab flooring units, was completing the day's curing of units. 170m prestressed hollow core flooring units were cast and cured in the open and the production of 10m long hammer driven piles.

General Impressions :

The standard of products and concrete was generally higher than expected, especially when the age of most of the equipment was considered. The supervision was generally good and the processes, etc. were more than adequate for the intended purpose.

APPENDIX 2

Lecture Programme

Venue : Lectures 1, 2, 8, 9 and 10 - Scientific Research Institute,
Yo Yang Lu.

Lectures 3, 4, 5, 6 and 7 - HQ Shanghai Science Association,
Nang Tun Lu.

A 15-minute intermission took place during each lecture.

1. October 31 : 09.00 to 11.35 hrs. The production and use of fly ash - a world review.
2. November 1 : 08.45 to 11.15 hrs. Quality of fly ash as it affects its use in concrete.
3. November 2 : 08.15 to 10.10 hrs. The techniques of testing fly ash.
4. November 3 : 08.20 to 10.20 hrs. The development of standards for fly ash and cements containing fly ash.
5. November 4 : 08.10 to 10.25 hrs. Mix design using fly ash.
6. November 5 : 13.30 to 15.15 hrs. Strength development and its measurement at early ages.
7. November 7 : 08.15 to 10.40 hrs. Corrosion of reinforcement in fly ash concrete.
8. November 8 : 08.15 to 10.10 hrs. Properties of fly ash concrete other than for strength.
9. November 9 : 08.20 to 09.55 hrs. Optimizing the amount of fly ash in concrete.
10. November 10 : 08.15 to 10.10 hrs. Research and testing techniques for fly ash and fly ash concrete.

Lectures 1 and 10 were chaired by Mr. Jiang Dian-Chang, Director, Chief Engineer, and the other lectures by Mr. Shen Dan-Shen, Deputy Chief Engineer of the Shanghai Building Science Research Institute. Numbers attending the lectures varied from about 80 to about 110. The interpreter for all the lectures was Mr. Gu Zhang-Zhao, Deputy Division Chief Senior Engineer of the Institute.

APPENDIX 3

Discussion Sessions

Venues : Shanghai Building Science Research Institute - 1, 2.
HQ Scientific Association - 3.
Scientific Research Institute - 4.

1. November 1 : 13.30 to 15.15 hrs. Meeting of the Chinese National Committee on the utilization of fly ash. Numbers present - 18. Was asked to speak about the promotion of fly ash use in the United Kingdom.
2. November 2 : 13.30 to 15.20 hrs. Shanghai Ready Mixed Concrete Industry. Numbers present - 24. Answered six written questions. Illustrated replies with slides.
3. November 4 : 10.45 to 12.00 hrs. General discussion on fly ash quality and standards. Numbers present - 18. Replies to five written questions.
4. November 8 : 10.30 to 11.45 hrs. General discussion on durability. Numbers present - 30. Replies to seven written questions.
5. November 9 : 13.30 to 15.45 hrs. General discussion on test methods and mechanical properties of fly ash concrete. Replies to four written questions. There was a long discussion on accelerated carbonation testing.
6. November 10 : 10.15 to 10.45 hrs. Discussion with Mr. Wu Liang-Zhi, Chief Engineer, Shanghai Construction Engineering Bureau, about the carbonation of concrete and its rate, particularly if it contains fly ash. Information was required on cements composed of 30% fly ash with granulated slag and Portland cement.

APPENDIX 4

Discussions with Shanghai Building Science Research Institute.

1. November 10 : 15.00 to 17.00 hrs. General discussion with Mr. Jiang and Mme Dai on the general programme of work with U.N.I.D.O. and the format of discussions that would take place at the Institute in the remaining days November 11 to 15.

The topics for discussion were to be :-

A. Marketing of fly ash

- i) Main points for marketing : manufacturing processes.
- ii) Technical aspects : the specification.
lagoon fly ash in U.K. and treatment.
site testing.
- iii) Site instruction for fly ash use : technical support.

B. A specification for fly ash in Shanghai

- i) Results of work at Institute on fly ash and fly ash concrete.
- ii) Seeking ideas on a local standard.
- iii) Opinions on the adequacy of present research.
- iv) Is more research needed.
- v) Testing parameters.

C. A code of practice for fly ash use in concrete

- i) Properties of raw materials; cement; fine aggregate; fly ash, etc.
- ii) Requirements for depth of cover, etc. related to present code.
- iii) Limitations of use (if any) in structural concrete.
- iv) Provision in code for a) prevention of bleeding.
b) correct mixing.
c) workmanship.

D. Rapid test methods

To answer questions on the details of the methods of test presented. (A 17 page document detailing the test methods, both rapid and standard, was under consideration).

E. Research techniques

- i) Carbonation.
- ii) Permeability.
- iii) Performance of concrete that has undergone heat cycles.

2. November 11 : 08.30 to 11.30 hrs. 13.30 to 16.15 hrs.
Topic B. was exhaustively discussed both morning and afternoon. Rapid tests would help to decide on the grade of ash to be produced, and any requirements to reduce variability. Possibly the 45 μ m sieve residue could be $>15\% <30\%$, with water requirement 98 to 102%. For structural concrete the use of a water reducing agent is very important in order to reduce the water requirement of concrete.
3. November 12 : 08.30 to 11.30 hrs. 13.45 to 16.20 hrs.
Topic C. Concentrated on carbonation and its reduction in reinforced and prestressed concrete thin elements with minimum sizes <30 cm and the difficulties of relating accelerated tests to the performance of concrete in structures. The decision to relate fly ash concrete with slag cement concretes. Minimum cement and fly ash contents. Durability grades and nominated mixes with a built-in security. Testing of concrete and batching plant print out.
4. November 14 : 08.30 to 11.30 hrs. 14.15 to 16.15 hrs.
Topic C. Use of fly ash as a fine aggregate and how it would be incorporated by mix design techniques. Fly ash in cement manufacture.
Topic D. Rapid testing techniques, practical aspects of the test methods presented. Need for experience before doing comparative trials against existing standard procedures.
Topic E. Research techniques. Methods of simulated temperature induction. Temperature matched curing apparatus. The effects of temperature on concrete properties.
Topic A. Marketing of fly ash. Promotion of ideas in technical journals. News items. Practice sheets on all aspects - handling, storing, mixing, etc. Technical meetings, educational interest via the environmental necessity.
5. November 15 : 14.00 to 16.30 hrs. Shown a new film on fly ash and its use in the Shanghai region. It was an excellent production because it showed the production and applications with a very candid and explicit display of the present disposal difficulties. This film was in advance of most similar productions as it showed both sides of the problem.

APPENDIX 5

A proposal for comprehensive ash utilization

The following idea was presented during Lecture 9; whilst in detail there may be some inadequacies, it is the principle that can be developed.

The example considered the amount of fly ash that would be produced by a 3000 MW coal burning power station with 22% ash in the coal. It was estimated that about 11,000 Te of ash per day would be produced. Estimated annual output = $0.011 \times 85\% \times 365$ or about 3.4×10^6 Te. Assumed 20% is furnace bottom ash = $3.4 \times 10^6 \times 0.20 = 0.68 \times 10^6$ Te, therefore 2.72×10^6 tonnes of fly ash.

Fine fly ash average fineness 22½% 45 µm sieve residue = $2.72 \times 10^6 \times 0.15$ or 0.41×10^6 Te, 2.31×10^6 Te coarse fly ash.

To absorb 0.41×10^6 Te of fine fly ash, a cement plant needs to produce about 1.0×10^6 Te of clinker.

Coarse fly ash for raw feed = 0.30×10^6 Te with cement at 1.08×10^6 Te, say 30% bagged at 25% interground = 0.10×10^6 Te therefore total cement factory use = 0.40×10^6 Te

coarse fly ash remaining 1.91×10^6 Te.

Estimated uses in Grouts and base mix	0.2×10^6 Te
filler	0.1×10^6 Te
concrete masonry and bricks	0.2×10^6 Te
big blocks, panels & AAC	0.3×10^6 Te
lightweight mortars, etc.	0.1×10^6 Te
Total	0.9×10^6 Te

To absorb the remaining coarse fly ash it would need a lightweight aggregate plant working, say, 310 days / year or using 3250 Te / day or 135 Te / hours requires three units producing at 45 Te / hour. This would be the largest lightweight aggregate plant in the world.

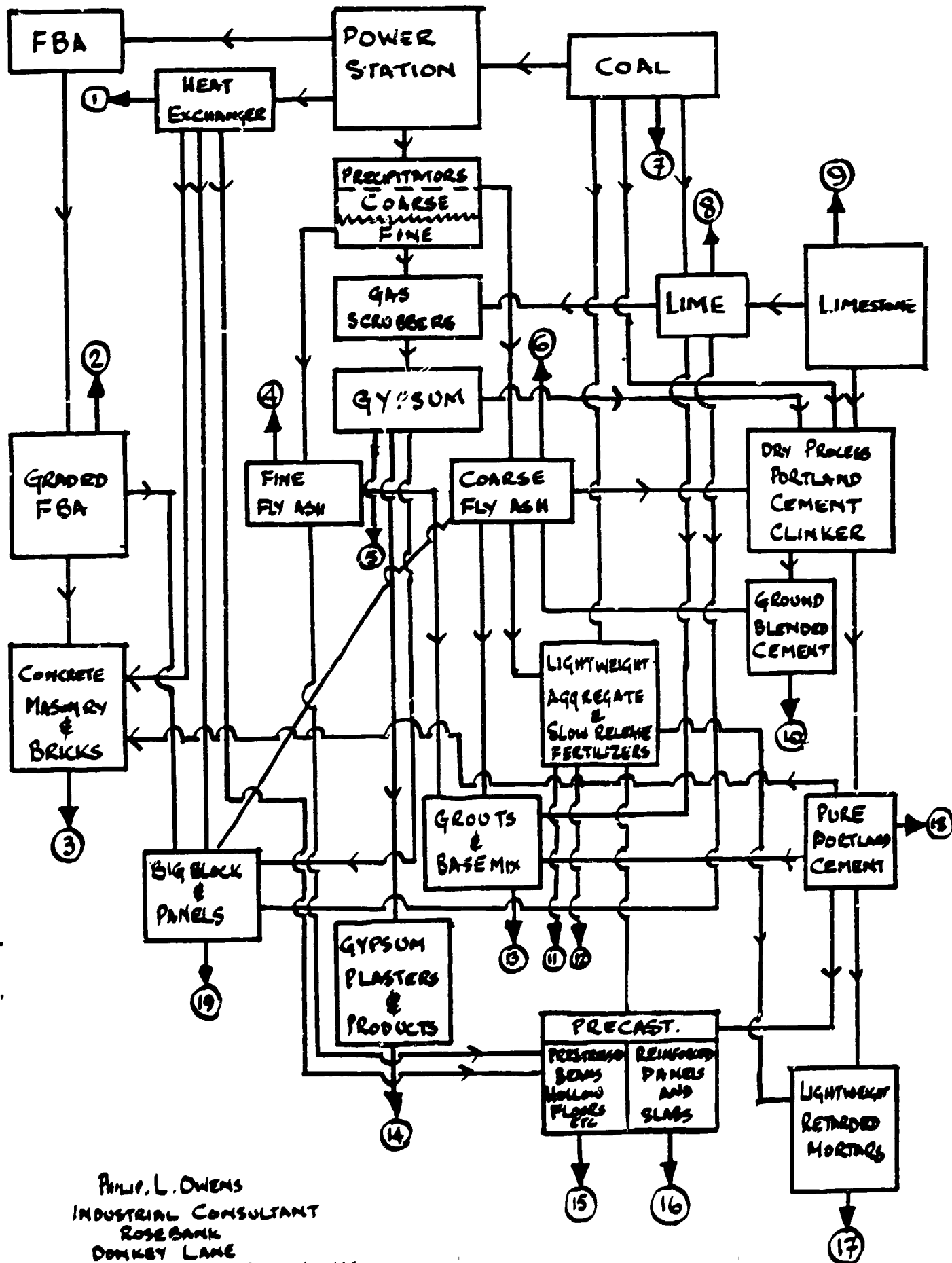
The list of products from both power stations and associated industries might be :

1. Heat exchanger for low pressure steam.
2. Fine fly ash for pozzolana and fine filler.
3. Gypsum.
4. Coarse fly ash - fine aggregate and general purpose filler.
5. Pulverized coal for industrial boilers, although the priority of the coal should be considered.

6. Lime.
7. Graded limestone aggregates.
8. Graded furnace bottom ash.
9. Interground blended cement; bagged supplies.
10. Lightweight aggregates for concrete, etc.
11. Slow release fertilizer pellets.
12. Concrete masonry and bricks.
13. Big blocks, panels and autoclaved products.
14. Grouts and basemix.
15. Gypsum plasters and products.
16. Portland cement.
17. Prestressed lightweight bridge beams, railway sleepers and hollow floors.
18. Reinforced precast elements.
19. Lightweight mortars and screeds.

The schematic drawing of the integrated processes is shown in Figure 1.

FIGURE 1 : Suggested comprehensive solution to the utilization of waste products from thermal coal burning power stations as it may apply in Shanghai, Chinese Peoples' Republic.



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