ICUS REPORT 2006 - 05

INTERNATIONAL CENTER FOR URBAN SAFETY ENGINEERING

INSTITUTE OF INDUSTRIAL SCIENCE
THE UNIVERSITY OF TOKYO

REPORT ON APPLICATION OF FLY ASH AS CONCRETE INGREDIENT IN THAILAND AND JAPAN

- Development and Current Situation -

Written by

Raktipong Sahamitmongkol, Yoshitaka Kato, Isao Kurashige,
Somnuk Tangtermsirikul and Taketo Uomoto
ICUS, IIS, The University of Tokyo, Japan

ISBN4-903661-04-0

Serial Number 17

Report on Application of Fly Ash as Concrete Ingredient in Thailand and Japan
- Development and Current Situation –

Written by

Raktipong Sahamitmongkol, Yoshitaka Kato, Isao Kurashige,
Somnuk Tangtermsirikul and Taketo Uomoto

International Center for Urban Safety Engineering (ICUS),
IIS, The University of Tokyo, Japan

ICUS Report No. 17
December 2006

APPLICATION OF FLY ASH AS CONCRETE INGREDIENT IN THAILAND AND JAPAN - DEVELOPMENT AND CURRENT SITUATION -

RAKTIPONG SAHAMITMONGKOL
Regional Network for Urban Safety (RNUS),
Asian Institute of Technology, Thailand
YOSHITAKA KATO
International Center for Urban Safety (ICUS),
Institute of Industrial Science, The University of Tokyo, Japan
ISAO KURASHIGE
Central Research Institute of Electric Power Industry, Japan
SOMNUK TANGTERMSIRIKUL
Sirindhorn International Institute of Technology,
Thammasat University, Thailand
TAKETO UOMOTO
International Center for Urban Safety (ICUS),
Institute of Industrial Science, The University of Tokyo, Japan

ICUS Report No. 17, December 2006

PREFACE

The sustainable development considering not only construction of durable infrastructure but also issues on environment and energy reservation is highly regarded recently. To meet these goals simultaneously, the application of by-product waste in construction materials or as fuels is the most promising approach. In this report, the utilization of fly ash which is the by-product of electric power generating plant in cement and concrete industry is summarized. The information from Thailand at which almost all fly ash is now being used as cement substituting additive and Japan where environmental issues and limited landfill space is the serious matters is discussed.

The comparison of the properties of the material itself, the history of fly ash usage, and current situation of applying fly ash in cement and concrete industry of both countries is done. In Thailand, the fly ash concrete is so popular that most of ready-mixed concrete plants have silos for fly ash. In Japan, on the other hand, the fly ash is usually used as the raw material for cement production which may face the limit as the demand of cement decrease and the treat from usage of municipal waste's ash to produce eco-cement.

This report aims to review the general view of fly ash application by considering also the difference in resources, technology, governmental policy on environment and energy.

Table of Contents

APPLICATION OF FLY ASH AS CONCRETE INGREDIENT IN THAILAND AND JAPAN - DEVELOPMENT AND CURRENT SITUATION -

RAKTIPONG SAHAMITMONGKOL
Regional Network for Urban Safety (RNUS),
Asian Institute of Technology, Thailand
YOSHITAKA KATO
International Center for Urban Safety (ICUS),
Institute of Industrial Science, The University of Tokyo, Japan
ISAO KURASHIGE
Central Research Institute of Electric Power Industry, Japan
SOMNUK TANGTERMSIRIKUL
Sirindhorn International Institute of Technology,
Thammasat University, Thailand
TAKETO UOMOTO
International Center for Urban Safety (ICUS),
Institute of Industrial Science, The University of Tokyo, Japan

INTRODUCTION

Though there have been worldwide studies, indicating the benefit of using fly ash in concrete, fly ash has still not been effectively utilized in most countries until now due to many reasons. The difficulties to promote the usage of fly ash in concrete are highly dependent on the history of concrete industry and policies about energy and natural resource reservation of each country. At present (2006), almost all fly ash produced in Thailand is used as a partial cement substitution material for both quality improvement and cost reduction of concrete. Thailand is one of the most successful countries in regard of the effective use of fly ash in concrete industry. This report states the efforts of researchers and engineers in Thailand in paving ways for the construction societies in Thailand to the effective use of fly ash and making comparison with current situation of fly application in cement and concrete industry in Japan. At the end, the example of employment of fly ash concrete to construct the biggest RCC dam in Thailand is described as an example of creative usage of fly ash concrete.

1. SITUATION OF CONSTRUCTION INDUSTRY OF THAILAND

It may be most appropriate to illustrate situation of construction industry in Thailand in term of yearly budget for construction. In Thailand, the budget for construction of new structure and maintenance work for existing structure is decentralized to many organizations and departments. Bangkok Metropolitan Administration Office (BMA), Department of Public Works and Town & Country Planning, and Department of Highways are few examples of the main organizations related to the construction of infrastructure of Thailand. In this report, the information from Department of Highways (DOH) will be mainly referred.

Figure 1 shows the data of total national budget of Thailand and budget of DOH) from 1970 to 2005. The budget for construction and maintenance work is less than 10% (see Figure 2). The budget for construction and maintenance is therefore limited when compared with the increasing number of infrastructure. Besides to the limited budget, the larger portion of the budget has been spent for the maintenance works in recent years.

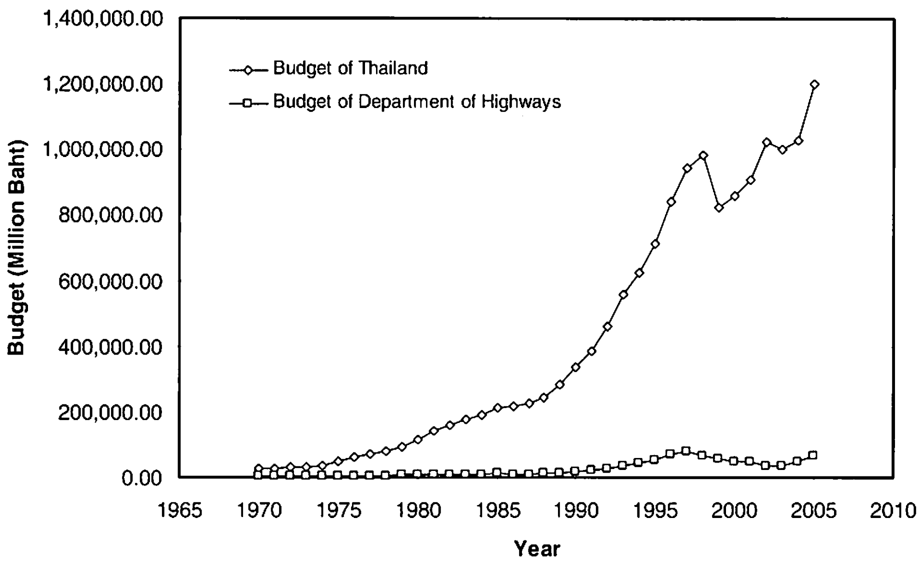


Figure1: National Budget and Budget of Department of Highways

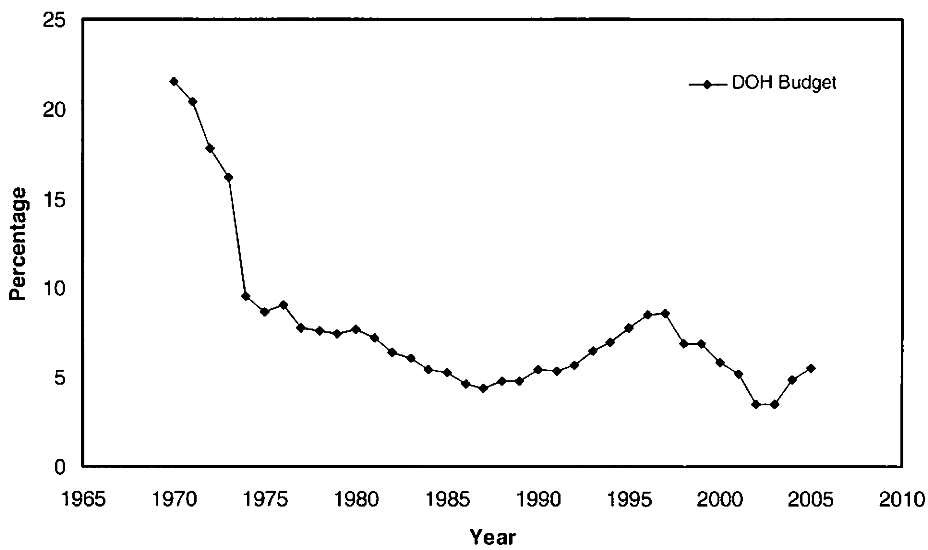


Figure 2: Ratio of DOH Budget to National Budget (Thailand)
(The value of year 2000 is the forecasted one)

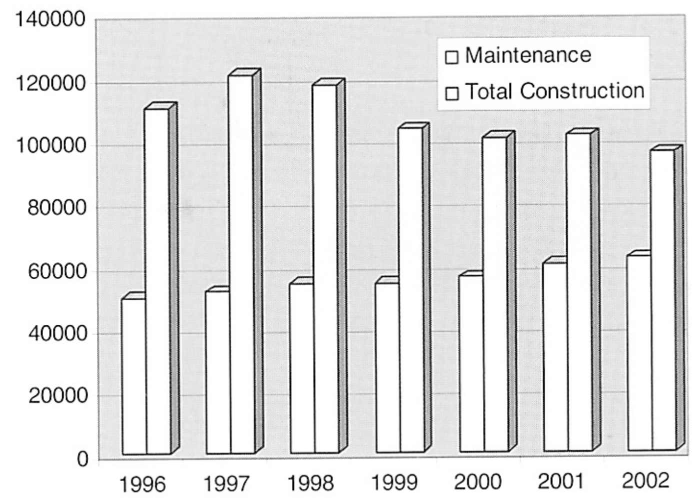


Figure 3: Total Budget of DOH and Budget spent for Maintenance Works (1996 – 2002)

In order to prepare for the difficult situation of construction industry in near future, the construction materials which can save construction cost and at the same time provide more durability of the structure is important. Using fly ash which is a by-product from the power generating plant in the production of concrete is one promising ways to achieve those goals. In this report, the usage of fly ash in construction in Thailand will be discussed.

2. HISTORY OF FLY ASH APPLICATION IN CONCRETE INDUSTRY

Fly ash was firstly introduced to concrete industry around 1930s. Davis et al [1] published the research about properties of cement paste and concrete that contain fly ash in 1937. An example of the application of fly ash in construction is the construction of Hungry Horse Dam (Montana State, USA) in 1948 [2]. The research and practical usage became wide-spread when the price of gasoline became higher and higher and when the environmental impacts gained more awareness. American Concrete Institute (ACI) published the document ACI 232.2R-96, 'Use of Fly Ash in Concrete' [3] to replace the ACI 226.3R-87. In a similar manner, Canada Centre for Mineral and Energy Technology (CANMET) revised the book named 'Fly Ash in Concrete' [4] in 1994 to replace the older version which is published in 1985. Furthermore, RILEM [5] published the technical book 'Fly Ash in Concrete, Proportion, and Performance' in year 1991. These three books together include more than 1,000 technical reports and research documents about application of fly ash in concrete. It is estimated that the usage of fly ash should increase in near future because of the rising demand of electric supply and 800 million tons of fly ash should be produced worldwide in 2010 [4].

2.1 History of Fly Ash Application in Japan [6]

The application of fly ash in construction field was firstly considered around 1955. The fly ash was firstly applied as an additive to conventional concrete. Based on several researches about fly ash concrete during that period, some dams were constructed from fly ash concrete. In 1970, the usage of gasoline was gaining popularity and the amount of generated fly ash temporarily decreased and the development of application technique became stagnant. However, the usage of coal as the fuel was promoted again after oil shocks. With the improved quality of the coal power electricity-generation plant, the amount of imported coal continued increasing and the amount of generated fly ash has been increasing every year.

The fly ash can be consumed in various fields as shown in Table 1. However, cement and concrete industry is the largest consumer of fly ash. It usually consumes more than 60% of total consumed amount of fly ash in Japan and most countries worldwide. In 2000, Japan use approximately 4.9 million ton of fly ash in cement and concrete industry alone.

Table 1: Field that fly ash is applicable

Fields	Usage
Cement and Concrete Industry	Ingredient of cement production, Blended cement component, Pozzolanic additives
Civil Engineering	Foundation improving materials, Road foundation material, Asphalt Ingredient, Filler material, etc.
Architecture	Housing panels, Artificial light-weight aggregate
Agriculture	Fertilizer, Soil adjustment
Others	Waste water filter, etc.

2.2 History of Fly Ash Application in Thailand

The research about usage of fly ash in Thailand started approximately 20 year ago. In 1980 and 1983, P. Jirappapa [7, 8] published the first research documents about fly ash in Thailand. Subsequently, P. Chindaprasirt [9, 10] and his team present their research work on usage of fly ash in !984 and 1985. Fly ash started to gain its popularity after that. In 1992, 100 thousand tons of fly ash (from Mae Moh power plant) was applied to create the foundation of 30,000 m^2 in order to carry the weight of all electrical devices in Mae Moh electric power station and the performance of this foundation has been monitored [11].

With strong support of Electricity Generating Authority of Thailand (EGAT) [12], the considerable amount of fly ash has been applied to real construction. Enough national research is a good basis for promoting the efficient usage of fly ash in commercial sector. The research group who focused on 'the Promotion of Lignite Fly Ash to Practical Use in Thailand' won the 'Excellent Technologist Award' in 2002 from Science and Technology Promotion Foundation under Royal Patronage [13]. Thai researchers have also recently published the research works on fly ash concrete in international journal [14-16]. In addition, the Engineering

Institute of Thailand under H.M. the King's Patronage (EIT) published the book 'Application of Fly Ash in Concrete' (in Thai language) and Thai Concrete Association (TCA) also published another book 'Fly Ash in Concrete Work' (in Thai language) to provide technical knowledge to interested engineers.

In Thailand, the amount of fly ash produced annually is approximately 3 million tons during the past 10 years. About 95% of the total production is produced from the Mae Moh generating plant of the Electricity Generating Authority of Thailand (EGAT) in Lampang province, in the north of Thailand. While, the rest of fly ashes are produced near Bangkok. An example of application of Fly Ash in Mega-project construction in Thailand is the construction of Klong Tha Dan Dam (completed in 2003) in which the roller compacted concrete (RCC) containing high amount of fly ash.

3. MERITS OF APPLYING FLY ASH AS CEMENT SUBSTITUTING MATERIAL

Fly ash is one of the by-products produced from the process of coal burning. Electricity generating using coal as the energy source is the main industry which produces fly ash as its major solid waste. There are still other types of solid wastes produced from the coal generating plants like bottom ash and gypsum but their volumes are generally far less than that of the fly ash. There are difficulties around the world to achieve effective utilization of fly ash or even to get rid of it. Majority of the fly ash is dumped or used in low-valued methods such as using as a land-fill material, soil improvement, road base, land reclamation, raw material for producing cement. Some high-valued methods of using are available such as used as fertilizer, as filler in plastics and resins, as metal matrix composite (ceramic additives) [17], etc., but only a little amount of fly ash can be consumed in such utilization. The most effective use of fly ash at present, by considering both volume and value, is still in the area of concrete. The use of fly ash as a cement substituting material is believed to be beneficial by various reasons. In an environmental aspect, the cement substitution reduces the depletion of natural resources used for cement production. It also reduces the energy used for clinkerization, then reduces the gases emitted to the environment especially CO_2. It is estimated that abut 1 ton of CO_2 is released per a ton of clinker produced [18]. Although some properties of fly ash concrete, such as initial strength, carbonation and freezing and thawing resistance, have been found to be inferior than the concrete without fly ash, the use of fly ash to partially replace cement improves many properties of concrete especially durability properties such as increasing workability and pumpability, improving long-term strength, reducing temperature, reducing shrinkage, improving resistance against chloride-induced steel corrosion, increasing sulfate resistance, reducing risk due to alkali-aggregate reaction, etc [19-25]. A proper use of fly ash based on the type of construction work and the service environment that the constructed structure is located is considered to be most rational.

4. GENERAL INFORMATION OF FLY ASH IN THAILAND AND JAPAN

In this section, some comparative studies are conducted to compare the general trend of characteristics of fly ash produced in Thailand and Japan. The properties of Thai fly ash are obtained from the testing of Mae Moh fly ash while the properties of Japanese fly ashes were obtained from fly ashes from various sources [26].

4.1 Comparison between Characteristics of Thai Fly Ash and Japanese Fly Ash

4.1.1 Chemical Composition

Table 2 compares the ranges of chemical composition of fly ash in Japan and Thailand. The data of Thai fly ashes are those observed continuously for more than 10 years. The data of Japanese fly ashes, though were obtained from a single study, covered large enough sample types and sources i.e. 40 types of fly ash from 24 generating plants in Japan [26]. It can be seen that the chemical composition of fly ash in Thailand covers a wider range than that of Japan. This is mainly because, in addition of the differences of the types of the plants and processes, Thailand uses many sources of coal both local and imported ones. The biggest local source is in Mae Moh, Lampang province, which is located in the north of Thailand. The coal used in Mae Moh is lignite while most of the imported coals are anthracite or bituminous coals. It is noted that for the Mae Moh fly ash, which comprises of 95% of the total fly ash produced in Thailand, the scattering of the chemical composition is not much.

From Table 2, most of the Thai fly ashes have lower SiO_2 content, larger CaO and alkali content than the Japanese fly ash. Though the data on SO_3 content of the Japaneses fly ash does not appear in the Table, it is realized that most of the Thai fly ashes have rather high SO_3 content. It must be noted here that the high CaO and high SO_3 fly ash mostly belongs to the Mae Moh power plant where lignite coal is used.

Table 2: Comparison of Chemical Compostion between Fly Ashes in Japan and Thailand

Composition	**Japan* (%)**	**Thailand** (%)**
SiO_2	47-70	20-55
CaO	0.49-7.55	1-35 (majority 7-20)
Al_2O_3	15.64-32.03	5-40
Fe_2O_3	2.54-15.68 (majority<5.0)	1-15
SO_3	-	0^+-10 (majority between 1.5-4.0)
MgO	0.22-2.81	0^+-5
$(Na_2O+0.658K_2O)$	0.22-3.27 (majority <1.5)	0.5-2.5 (majority >1.5)

* from reference [26]

** from reference [27] and the Electricity Generating Authority of Thailand.

4.1.2 Physical Properties and Loss on Ignition

Table 3 compares some physical properties and loss on ignition between the Japanese and Thai fly ashes. It can be observed from the Table that the majority of the Thai fly ashes have lower specific gravity, Blaine fineness and loss on ignition than the Japanese fly ashes. From the data of Blaine fineness and the amount retained on sieve#325, the Thai fly ashes are thought to be coarser. However lower specific gravity of the Thai fly ashes denotes that the Thai fly ashes have more cenospheres and plerosheres. The lower loss on ignition of the Thai fly ashes is considered to be due to higher allowable burning temperature of the coal powder in Thailand than that allowed in Japan due to the limitation of the emission.

Table 3: Comparison of Physical Properties between Fly Ashes in Japan and Thailand

Properties	**Japan* (%)**	**Thailand** (%)**
Specific gravity (g/cm^3)	1.98-2.43	1.7 - 2.4 (almost half <2.0)
Blaine fineness (cm^2/g)	2350-6580	1800 – 4000 (about 80% <2500)
		20 - 65
% Retained on sieve #325	4.8-53.9	0.1 – 5 (about 80%<1.0)
Loss on ignition (%)	0.4-13.9	

* from reference [26]

** from reference [27] and the Concrete Products and Aggregates Co.ltd

4.2 Properties of Paste, Mortars and Concrete using Fly Ash

4.2.1 Water Requirement

Table 4 shows the comparison of water requirement between the Thai fly ashes and the Japanese fly ashes. It should be noted here that the test methods of both countries are not the same (JIS A6201-1991 was used to test the Japanese fly ashes and ASTM C311 was used to test the Thai fly ash). Mix proportion of the test samples, apparatus and the test procedure are all different. Especially for the mix proportion, in JIS A6201-1991, the water to binder ratio (W/B by weight) of the control sample (cement only mortar) is set at 0.65 and the sand to binder ratio is 2.0 while ASTM C311 specifies water to binder ratio of 0.484 and sand to binder ratio of 2.75. However, though both countries' fly ashes were tested based on different standards but they have the same concept to evaluate the test results. If the two set of data are compared by discarding the difference of the test methods, then both countries' fly ashes have similar water requirement as can be seen from Table 4. The lower loss on ignition makes the Thai fly ashes have similar level of water requirement to the Japanese fly ashes though they are coarser.

Table 4: Comparison of Water Requirement between Fly Ashes in Japan and Thailand

Properties	Japan* (%)	Thailand** (%)
Water requirement (%of the control)	91-105 (majority <100%)	93-103(majority <100%)

* from reference [26], tested by JIS A6201-1991
** data from the Concrete Products and Aggregates Co.ltd., tested by ASTM C311

4.2.2 Strength

The strength properties of fly ashes were compared by using the strength index which is the ratio of compressive strength between the fly ash mixed mortar and the cement only mortar (control mixture) at the age of 28 days. As in the case of flow, the different test methods between the JIS A6201-91 and the ASTM C311 must be noted for preparing the test specimens in both countries. The most important difference is the w/b of the control mortar samples which is 0.65 for JIS A6201-91 and 0.5 for ASTM C311. This makes the two set of data not directly comparable. The JIS A6201-91 is supposed to give wider differences between the control and different fly ash samples due to lower strength of the control sample.

However, the evaluation concept of the test results is the same. Then if ignoring the difference of the mix proportion, it may be able to state that the Thai fly ashes are about the same as the Japanese fly ashes in terms of strength development up to 28 days even though they are coarser. It should be noted here that another test condition that is not similar is the curing temperature which is 20°C in Japan but is 23°C for the Thai data used in this report. However, this 3°C difference in the curing temperature can be considered to have negligible effect. The not lower strength of the Thai fly ashes is possibly due to the higher CaO content, as the major reason, and lower loss on ignition, as the minor reason, in most of the Thai fly ashes than the Japanese ones.

Table 5: Comparison of Strength Index between Fly Ashes in Japan and Thailand

Properties	Japan* (%)	Thailand** (%)
Strength index at 28 days (% of control)	57.8-97.8 (about 90% between 65-85)	65-100

* from reference [26], tested by JIS A6201-1991
** data from the Concrete Products and Aggregates Co.ltd., tested by ASTM C311

5. FLY ASH CONSUMPTION IN THAILAND

Figure 4 shows the fly ash consumption in concrete in Thailand. The consumption shown in the figure is only for those used as a cement replacing material in concrete. In Thailand, up to the time this report is being written, almost 100% of the fly ash consumption is for this purpose. It is expected that the consumption of fly ash in cement and concrete will still increase in the future.

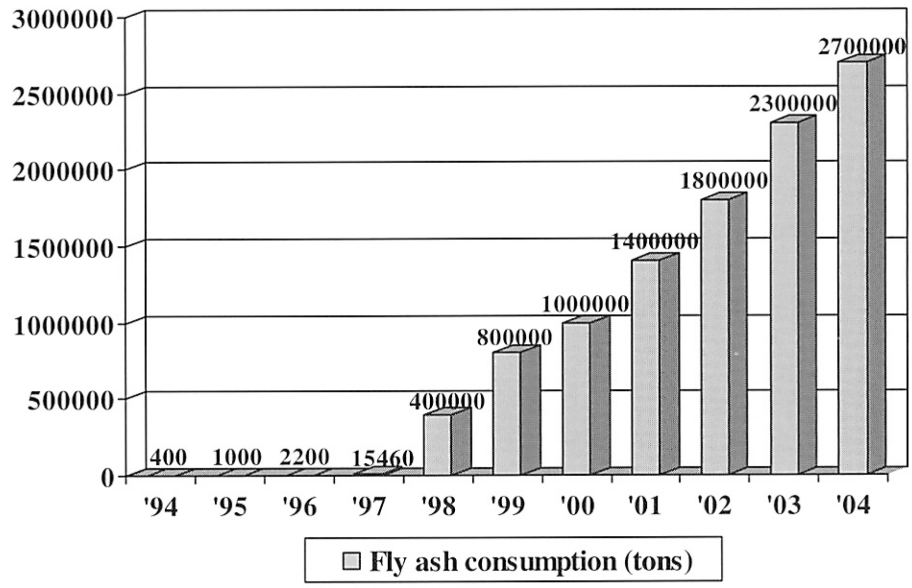


Figure 4: Fly ash consumption in concrete in Thailand (The value of year 2000 is the forecasted one)

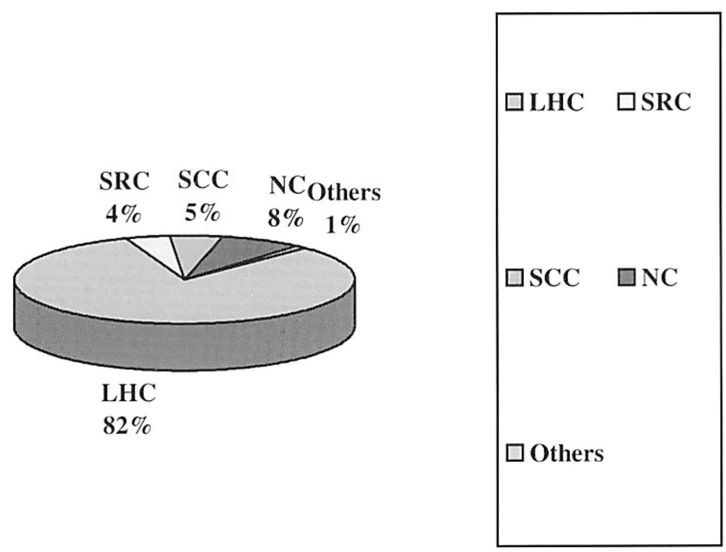


Figure 5: Distribution of fly ash used in various types of concrete from 1994-1997
LHC:Low heat concrete, SRC:Sulfate resisting concrete, SCC:Self compacting concrete, NC:Normal concrete

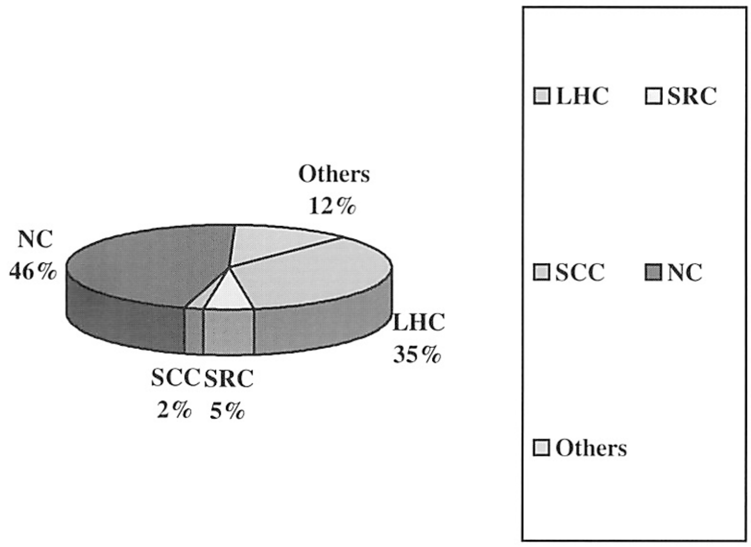


Figure 6: Distribution of fly ash used in various types of concrete in 1999 (forecasted from January to April 1999)
LHC:Low heat concrete, SRC:Sulfate resisting concrete, SCC:Self-compacting concrete, NC:Normal concrete

Figure 5 and Figure 6 show the statistics of fly ash used in various types of concrete. It can be seen from Fig.2 that up to 1997, fly ash was used mostly to produce special concrete like self- compacting concrete, sulfate resisting concrete and low heat concrete for mass concreting. However, the situation changes in 1999 when fly ash was used mostly in normal concrete. This expressed that fly ash had become more and more popular and engineers were more and more confident with the fly ash application in concrete at that time. At present, fly ash has already become a conventional cement replacing material in Thailand so that majority of the ready-mixed concrete plants, including those in precast concrete and on-site ready mixed plants, are using it as a major cementitious material and fly ash concrete has now become a conventional concrete in Thailand.

5.1 Problems to Promote the use of Fly Ash in Thailand

During 1980's, the image of fly ash produced from Mae Moh was negative due to many technical reports which pointed out the volume instability of concrete using fly ash due to high SO_3 content in the fly ash (mostly in the range of higher than 5% by weight of the fly ash) [28, 29]. Therefore the uses of fly ash at that time were in the low-value manners such as used for soil improvement, for embankment slope stability, for sub-base of pavement, for concreting of temporally pavement, etc. It was until the early 1990's that the SO_3 content of fly ash became lower to conservative values of below 5%. From that time, various intensive researches were restarted and many merits were found from using the fly ash in concrete as mentioned earlier in the section of introduction. In spite of the positive study results, fly ash was very little used in concrete production until 1997 (see Fig.1) due to many reasons as follows.

1) Lack of understanding and knowledge on fly ash among the engineers
2) Doubt on fly ash quality and its consistency
3) No systematic supplying system to facilitate the use.

5.2 Strategies to Promote usage of Fly Ash in Concrete Industry

Many efforts were made by the Committee on Concrete and Materials of the Engineering Institute of Thailand to promote the use of fly ash in Thailand.

5.2.1 Research

An original research group consisting of researchers from 7 universities in Thailand was formed to study the properties of fly ash and concrete using fly ash. By this original group, more than 30 research reports and more than 100 technical papers had been already published until 2000. After that many other universities also started to conduct research on fly ash and many more publications have been produced since then.

5.2.2 Education and Training

From 1994 to 2001, eight seminars were arranged, by the committee, in various places around the country to give information and educate engineers on the effective use of fly ash in concrete. A learn-on-line project was created by the cooperation between the National Science and Technology Development Agency, the Electricity Generating Authority of Thailand and the Joint Research Group to provide information in a more effective and broadened way [30]. Many books and documents were also published for the purpose of educating engineers in the country [27,31]

5.2.3 Support for Real Practice

Various efforts were made to provide support for real application as follows

1) Conducting demonstration construction using fly ash concrete. Many demonstration construction projects were conducted during 1992 to 1996 (see Figs. 4, 5 and 6) to provide information.

2) Set up a unit called "By-Product Business Unit" at the Mae Moh generating plant for supplying business and quality control of fly ash. For quality control, the fine coal used for boiler burning is blended from various locations and layers of coal mines in Mae Moh in order to satisfy the requirement of energy output as well as to obtain fly ash with constant properties. At the moment, the measured properties of fly ash for quality control at Mae Moh are CaO, SiO_2 and SO_3 contents. It is expected that fineness will be another measured value for quality control at Mae Moh in the near future. Since fly ash is not an industrial product but a by-product, the qualities of fly ash is expected to vary and be not constant like cement. The variation in properties is one of the main hurdles for fly ash using in many parts of the world, not excepting Thailand.

This system of quality control at the origin together with the coal blending technique will help reducing the uncertainty of fly ash quality and provide confidence to the users.

3) Provision of standard for fly ash. One of the problems at the beginning of fly ash application is the lack of appropriate standard that suited the local fly ash. According to many foreign standards, the properties of Thai fly ash especially the Mae Moh fly ash did not pass the requirement on fineness. However, researches had proved that though the fly ash had low fineness, it provided very satisfactory performance when used in concrete. Many performances are even better than fly ashes from many other countries. The committee on concrete and materials of the Engineering Institute of Thailand then decided to draft a new standard specification for fly ash in Thailand based on properties of Thai fly ashes and was published in 2003 [32]. Tables 6, 7 and 8 summarize the classes of fly ash and the corresponding chemical and physical requirements according to the latest Thai specification.

4) Produced references for practical engineers. Two books were published for being used as references for practical engineers [27, 31].

5) A software "FACOMP T1.0" was developed as a tool to facilitate the practical engineers for mix proportioning of fly ash concrete (see Figure 7).

6) Encouraged ready-mixed concrete company to launch special fly ash concrete products such as marine concrete, sulfate-resisting concrete, sulfate-resisting concrete, self-compacting concrete, low-heat concrete, etc.

Table 6: Chemical properties

Item	Properties	Requirement			
		First class	Second class		Third class
			Type a	Type b	
1	Silicon dioxide (SiO_2), min. %	30.0	30.0	30.0	30.0
2	Calcium oxide (CaO), %	-	Less than 10.0	Not less than 10.0	-
3	Sulfur trioxide (SO_3), max. %	5.0	5.0	5.0	5.0
4	Moisture content, max. %	3.0	3.0	2.0	3.0
5	LOI content, max. %	6.0 [1)]	6.0 [1)]	6.0 [1)]	12.0

Note: [1)] The use of fly ash with up to 12% LOI may be approved if either acceptable performance records or laboratory test results are made available.

Table 7: Chemical properties (optional)

Item	Properties	Requirement			
		First class	Second class		Third class
			Type a	Type b	
1	Alkali content ($Na_2O + 0.658K_2O$) [1], max. % 1.1 when SO_3 between 3.0 to 5.0 % 1.2 when SO_3 less than 3.0 %	 1.5 4.0	 1.5 4.0	 1.5 4.0	 1.5 4.0

Note: [1] Fly ash with alkali content exceeding this limitation may be approved if the test results on control of alkali-silica reaction satisfy the requirement.

Table 8: Physical properties

Item	Properties	Requirement			
		First class	Second class		Thir d class
			Type a	Type b	
1	Fineness (select a method) Amount retained on 45-μm-mesh sieve, max. % Or Blaine fineness, min. cm^2/g	 10 6000	 50 2300	 55 2000	 65 1600
2	Strength activity index [1] with OPC type 1 7-day, min. % of the control 28-day, min. % of the control 91-day, min. % of the control [2]	 85 95 100	 70 75 85	 70 75 85	 60 70 75
3	Water requirement, max. % of the control	102	105	105	108
4	Autoclave expansion [3], max. %	0.8	0.8	0.8	0.8

Figure 7: Demonstration of mass concreting using fly ash concrete at Mae Moh power generating plant

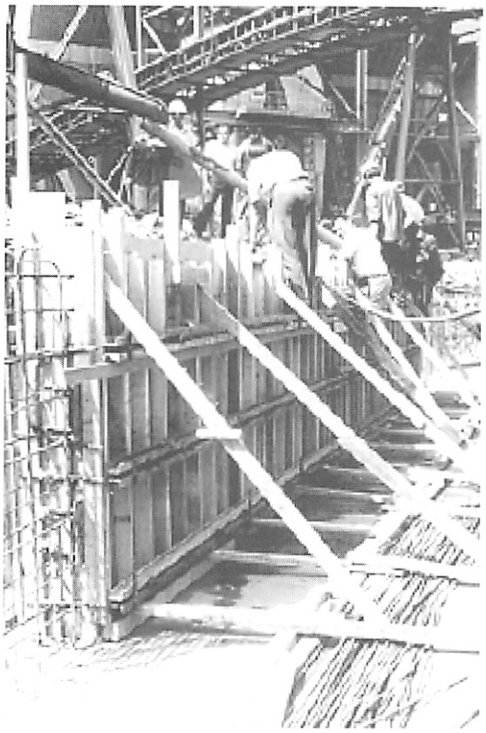


Figure 8a: Concrete wall

Figure 8b: Concrete box culvert

Figure 8: Demonstration of Self-Compacting Concrete using fly ash at Mae Moh power generating plant

Figure 9: Demonstration construction of Roller-Compacted Concrete Pavement using fly ash at Mae Moh power generating plant

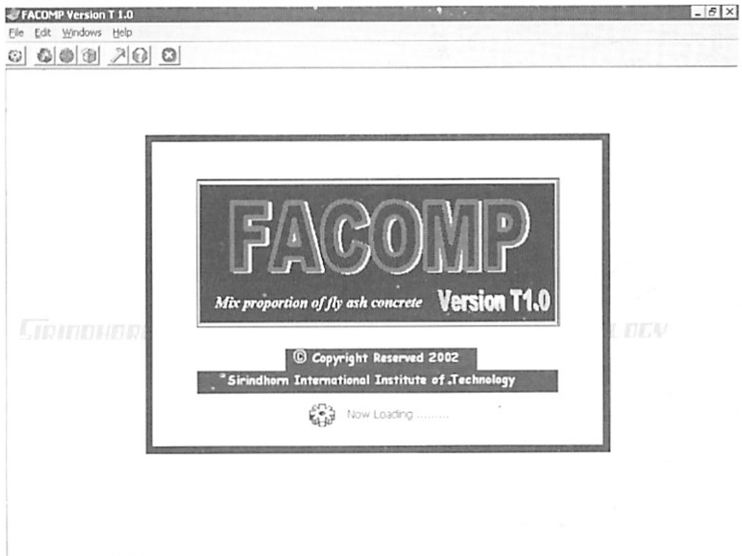


Figure 10: Computer software for mix proportioning of fly ash concrete

6. MIX PROPORTIONING OF FLY ASH CONCRETE IN THAILAND

Thailand has developed its own mix proportion design for fly ash concrete. In the design method, compressive strength and workability are two main factors considered. In this section, the mix proportioning of fly ash concrete is briefly reviewed.

6.1 Strength Prediction Model

The following parameters are used in the design for 28-day compressive strength of fly ash concrete.

- Total CaO content in binders
- Water to binder ratio
- Paste to void ratio (γ)

In order to predict the compressive strength of fly ash concrete at other ages, the strength development was also developed to predict the strength ratio based on 28-day compressive strength (strength ratio at 28 days is always 1 for all mix proportions). The following parameters are deemed to be significantly influence the strength development of compressive strength.

- Ratio between Silica dioxide to Calcium Dioxide (SiO2/CaO)
- Water to binder ratio
- Time

6.2 Workability Model

Workability of concrete can be tested in various methods. The most common method is the 'slump' test which is the most suitable test method for the concrete with usual range of workability. The following factors are included in the prediction for slump of fly ash concrete without any superplasticizer or water reducing agent.

- Paste to void ratio (γ)
- Total surface area of aggregates
- Total surface of binders
- Free water content

6.3 Mix Proportioning Procedures

In the mix design method, the compressive strength, water to binder ratio, and slump are all considered as the important targeted parameters to ensure the mechanical properties, durability, and workability of fly ash concrete. There are two methods of mix proportion for fly ash concrete which are 'Iterative Design Method' and 'Simplified Design Method'.

6.3.1 Iterative Design Method

The Iterative Design Method is the design method which is required the iteration to obtain the mix proportion. In this design method, the design chart is necessary to determine the amount of effective CaO to obtain the design compressive strength for a concrete with a given paste to void ratio (γ) (see Figure 11). The flowchart of this design method is shown in Figure 12.The detailed explanation is not included in this report. However, the full explanation and examples can be found in reference 27.

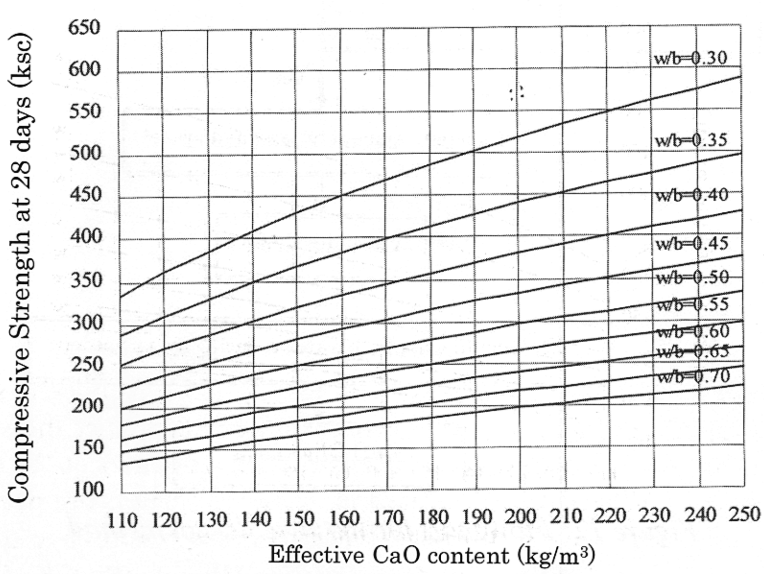


Figure 11: Design chart for mix proportioning based on iterative design method (for fly ash concrete with $\gamma = 1.10$) [27]

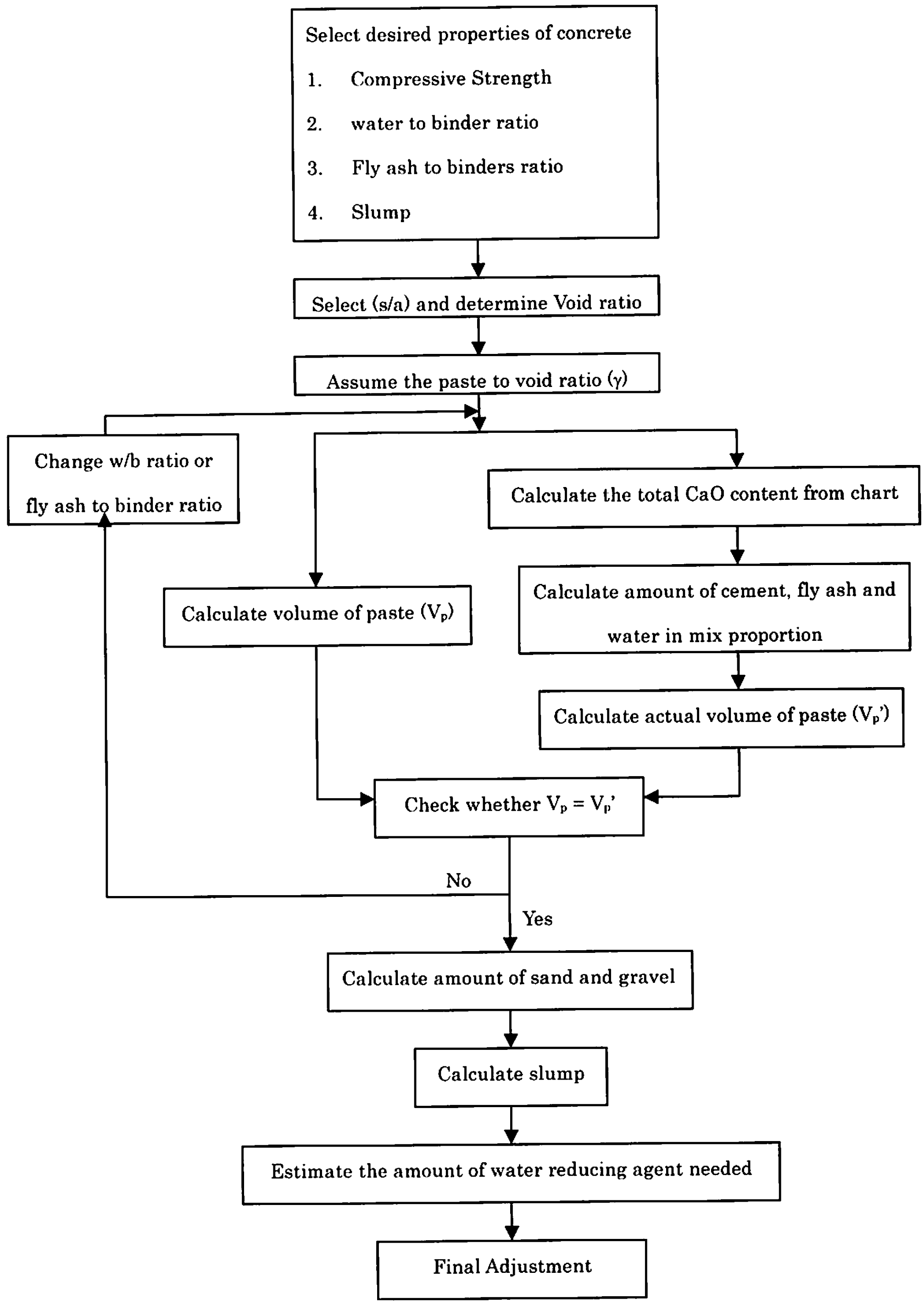


Figure 12: Flowchart for iterative design method

6.3.2 Simplified Design Method

The Simplified Design Method is the design method which is simplified so that the iteration is not necessary to calculate the mix proportion. The flowchart of this design method is shown in Figure 13. This method is based on more design charts to simplify the mix proportioning of fly ash concrete. These charts are composed of 'Design chart to calculate the equivalent CaO content required to obtain the desired compressive strength' (Figure 14), 'Design chart to determine the water retainability of binders from its specific surface area' (Figure 15), and 'Design chart to determine water retainability of aggregates' (Figure 16).

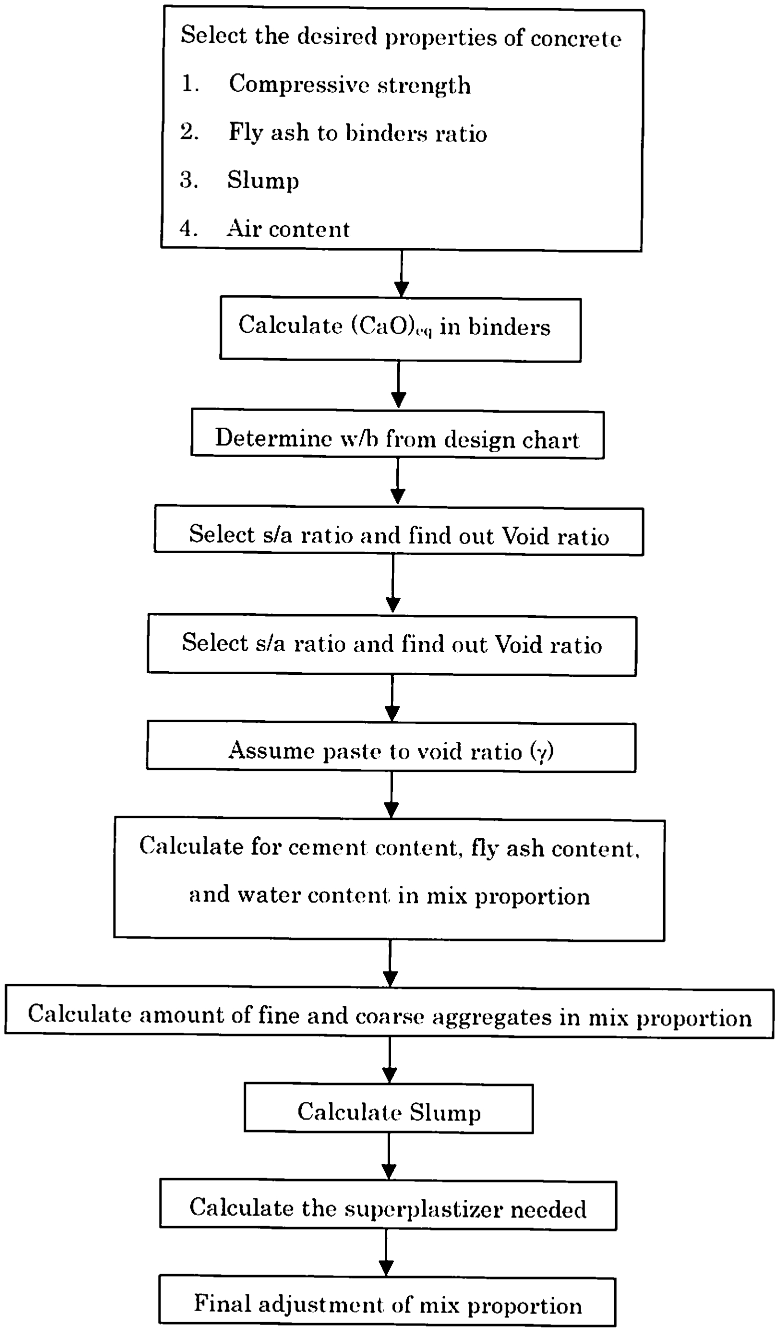


Figure 13: Flowchart of mix proportioning based on simplified method

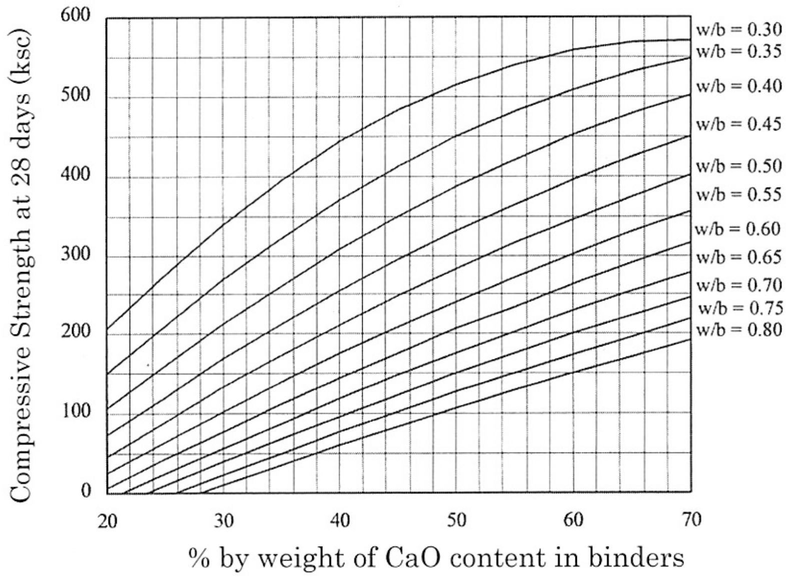


Figure 14: Design Chart for proportioning based on simplified method [27]

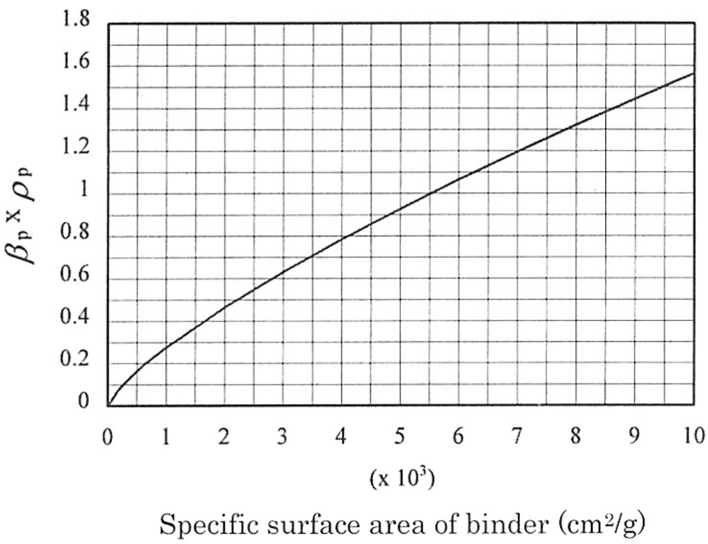


Figure 15: Design chart for the water-retaining ability of binders [27]
(β_p: water retainability of binders, ρ_p: specific gravity of binders)

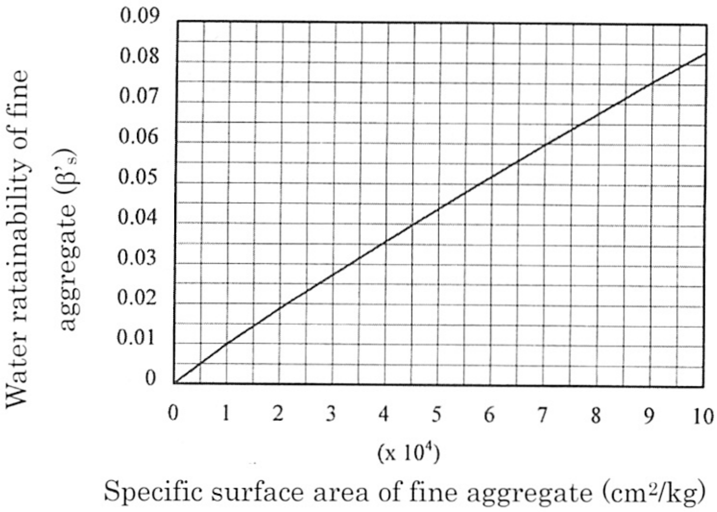


Figure 16: Design chart for the water-retaining ability of fine aggregate [27]

7. APPLICATION OF FLY ASH IN CONCRETE INDUSTRY OF THAILAND

Fly ash has become a popular cement replacing materials for concrete application since 1997 (see Figure 1) after the country faced economic crisis. One of the main reasons is that the cost of fly ash is much lower than that of the cement. The immediate gain from the low cost of fly ash could bring the great financial benefit. In Thailand, fly ash has been applied in various ways. This section is the summary of those applications.

7.1 Ready-Mixed Concrete

For ready-mixed concrete, fly ash is normally used to replace cement in the ranges of 20 to 30% by weight of the total cementitious materials. Fly ash concrete has become conventional concrete for ready-mixed concrete industry. As mentioned above, many ready-mixed concrete companies started to launch special concrete products with fly ash such as marine concrete, sulfate-resisting concrete, sulfate-resisting concrete, self-compacting concrete, low-heat concrete, since late 1990's. Some high volume fly ash concrete were also practiced in Thailand with the maximum fly ash content up to 55% of the total binders for self-compacting concrete, 47.5% for low-heat concrete and 68% for roller-compacted concrete (see Figure 17 for Pak Mool dam constructed using roller-compacted concrete). The ready-mixed concrete industry is now the major consumer of fly ash in Thailand.

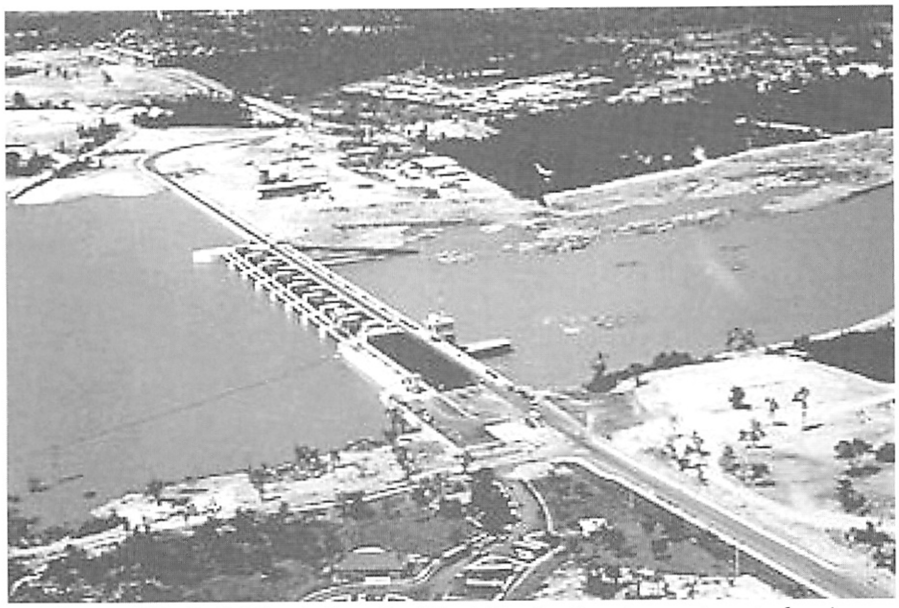


Figure 17: Pak Mool dam in Ubol Rachathani constructed using roller-compacted concrete with fly ash content of 68% of the total cementitious materials.

7.2 Precast Concrete and Concrete Products

For precast concrete and concrete product industries, fly ash is normally used in the works that does not require early strength such as non-prestressed concrete works. For prestressed concrete industries, fly ash is also used but with a maximum cement replacement of only up to 10%. The exception may be in the case of self-compacting concrete application in which fly ash may be used up to a range of 30% to 50% even in prestressed concrete work.

7.3 Other Cementitious Products

Some cementitious material products which use fly ash to replace cement in the production are such as cementitious fibered roof tile, cementitious fibered panel, etc. In this category, fly ash is normally used up to a maximum of 30% of the total cementitious materials.

7.4 Blended Cement

Some cement companies have made efforts to introduce ready-blended fly ash cement into the concrete market in Thailand. Most of them are introduced in the form of cement for durability purposes such as cement for marine environment having high resistance against sulfate attack and chloride-induced steel corrosion, sulfate-resisting cement or low-heat cement, etc. However, these cements are still not popular especially for project constructions using ready-mixed concrete. For projects, where ready-mixed concrete is usually applied, it is more popular to mix fly ash at the ready-mixed concrete plants. This is because of following reasons.

1) Ready-blended fly ash cement is more expensive than cement with fly ash as a separate binder

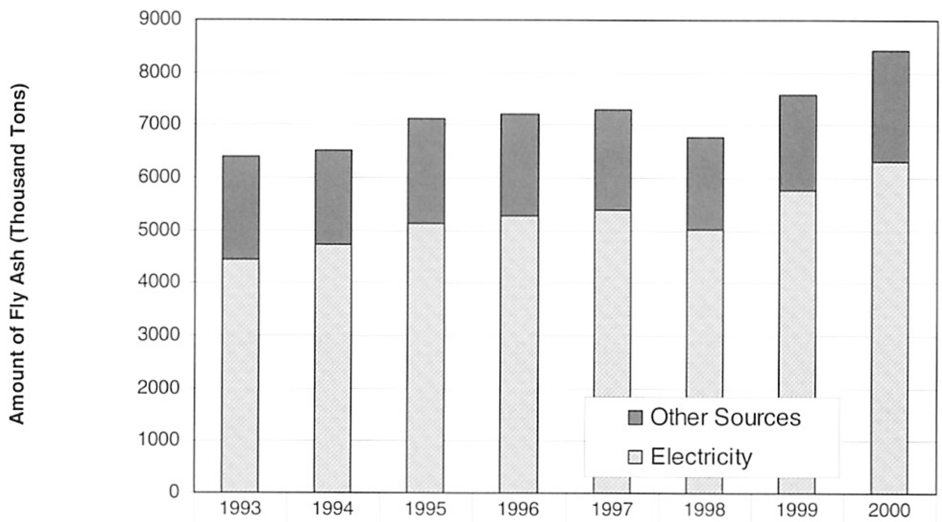
2) The ratio of fly ash is usually adjusted according to the required performances of concrete when it is used as a separate binder.

7.5 Repair Materials

Fly ash is also used in enhancing performances and reducing cost of some repair materials especially for grouting materials. Fly ash has also been studied as a stabilizer and to control expansion of expansive cement [33].

8. FLY ASH CONSUMPTION IN JAPAN

The amount of fly ash produced in Japan is increasing continuously as shown in Figure 18. Since most of fly ash is generated from the electricity generating plant, the amount of fly ash is therefore increasing proportionally to the electricity consumption rate of Japan. In 2002, the amount of fly ash produced in Japan is approximately 8.42 million tons of which 6.32 million tons was created by electricity generation (75%). From the estimated power demand of 3.9 GW in year 2014 which is 1.4 times of power supply of 2002. It is expected that the amount of fly ash generated from generation of electricity will increase to 8.885 million tons which will cause the shortage of space for landfill disposal of this amount of fly ash.



	1993	1994	1995	1996	1997	1998	1999	2000
Other Sources	1964	1801	1974	1920	1890	1760	1843	2097
Electricity	4438	4725	5149	5288	5408	5029	5757	6322

Figure 18: Total amount of fly ash produced in Japan until 2002

Table 8: Fly ash consumption in Japan classified by proposes

	1993	1994	1995	1996	1997	1998	1999	2000
Cement & Concrete	2,831	2,684	3,117	3,295	3,230	3,620	4,129	4,892
Civil Engineering	583	427	479	547	503	359	683	703
Architecture	254	320	289	384	356	289	283	364
Agriculture	99	165	139	95	93	89	131	144
Other	188	619	758	737	776	733	909	828
Total	3,955	4,215	4,782	5,058	4,958	5,090	6,135	6,931

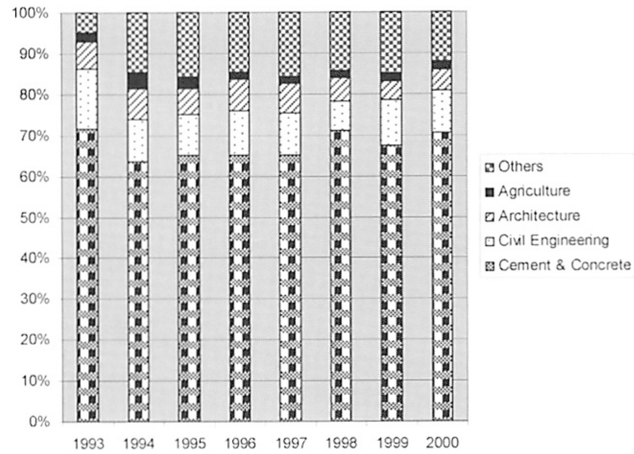


Figure 19: Percentage of fly ash consumption in each propose

Unlike the case of Thailand that almost all of fly ash is being consumed in cement and concrete industry as cement substituting material, fly ash in Japan is consumed by various proposes (see Table 8).

8.1 Usage of Fly Ash in Cement and Concrete Industry in Japan

Although the consumption of Japanese fly ash in cement and concrete industry is more than 60% (see Figure 19), the fly ash is used in three different manners, which are, as raw material for cement production, as component of blended cement (so-called fly ash cement), and as cement replacing additives in concrete.

8.1.1 Use of Fly Ash as a Raw Material for Cement Production

Fly ash can be used as replacement of clay in the production of cement. Because of comparatively high price of clay, natural resource reservation, the fly ash can be used as the substitution to clay due to its similar chemical component. In 2002, Japan produced approximately 80 million tons of cement were produced. For that amount of cement, 4.4 million ton of fly ash was used as an ingredient. As the possible usage capacity of fly ash for this objective is around 9.5% of produced cement, the current practice is therefore more than 60% of possible capacity already.

8.1.2 Use of Fly Ash to Produce Fly Ash Cement

Fly ash cement is one type of blended cement. To produce fly ash cement, fly ash (5% to 30% by weight of cement) is added to cement clinker during grinding process. This type of cement can suppress the alkali-aggregate reaction and reduce risk of thermal cracking in mass concrete. In year 2001, 0.5% of cement consumed is fly ash cement (0.392 million tons from 75.5 million ton of cement used). This amount is very small when compared with amount of slag cement consumed in the same year (17 million ton, 23%) and the usage amount of fly ash cement is also decreasing. The slag cement is more favorable because of the higher possible replacement ratio (30% to 60% by weight of cement), the negligible different properties of slag from different sources, and slightly cheaper price.

8.1.3 Use of Fly Ash as a Pozzolanic Additive in Concrete

Because fly ash improves the workability and durability when used as cement-replacing additive, it is popular to use fly ash concrete for construction of dam or structure which subjected to aggressive environment. In addition, using fly ash as an additive can lower the cost of special concrete like self-compacting concrete or shotcrete. In Japan, amount of fly ash is applied as cement substituting additive in concrete is gradually increasing. However, the amount of fly ash consumed in this way was around than 140,000 ton only in 2000 which is extremely little when compared with amount of consumed cement in the same year (80 million tons). It is general that the ready-mixed concrete plant does not have silo for fly ash. Additionally, the lower early-strength and requirement for longer curing of fly ash concrete may be other reasons of its infamy.

8.2 Problems of Applying Fly Ash in Cement and Concrete Industry in Japan

From the previous sections, it is clear that, although the usage of fly ash in cement and concrete industry is main consumption of fly ash both in Japan and Thailand. Japan uses most of its fly ash in cement production whereas Thailand used it mostly as the cement-substituting additive. The usage of fly ash to produce fly ash cement and to replace cement in concrete is limited to very special project like dam construction or other project where benefits of fly ash concrete is favorable. It is not common to order fly ash concrete from ready-mixed concrete plant in Japan.

The amount of fly ash used in the production of cement in Japan is 82% of fly ash consumed in cement and concrete industry in 1994 and 89% in 2000 although the close review on the cement production shows that, after the peak production of 99.26 million ton in 1996, the cement production has been continuously declined. The usage of fly ash in cement industry has been growing due to more usage in cement production (more replacement of clay). In 1996, this replacement ratio is 10% and became 23% in 2001 (more than double in 5 years). Nevertheless, in the production of 1 ton of cement, approximately 200 kg of clay is necessary. Fly ash can not completely replace clay because of its less SiO_2 and higher Al_2O_3; therefore the maximum replacement is limited to only 40% to 50%. It is possible that the usage of fly ash in cement production will hit its limit in very near future.

Another treat to usage of fly ash in cement production is the heavily promoted usage of municipal waste's ashes to produce cement (eco-cement). Although in the production of such new-type cement, the government have to pay 10-20 thousand yen to support the production, it is consider preferable when the impact on environment from the landfill of land. As the result, the usage of fly ash in Japan has to be adapted to more reasonable and productive while environment-friendly way in near future.

9. CASE STUDY ON USAGE OF FLY ASH TO SOLVE CONTRUCTION PROBLEM AT KHLONG THA DAN DAM, THAILAND

9.1 General Information of Khlong Tha Dan Dam

The Khlong Tha Dan dam is located at Ban Tha Dan, Hin Tang Sub-District, Muang District, Nakhon Nayok Province, Thailand. The project was initiated by His Majesty the King Bhumibol Adulyadej (Rama IX) of Thailand. His Majesty the King Bhumipol initiated Khlong Tha Dan Dam project to the Royal Irrigation Department of Thailand (RID). RID decided to construct Khlong Tha Dan Dam at Ban Tha Dan, Nakhon Nayok, Thailand. Khlong Tha Dan Dam is a roller compacted concrete (RCC) gravity dam with 93 m. in height, 2.72 km in length, which is the longest concrete dam in Thailand. The highest level of dam crest is +112 m. (msl) the highest level of reservoir capacity is +110 m. (msl) The reservoir capacity is 224 million cubic meters. Ninety percent of concrete is Roller Compacted Concrete (RCC) and the rest is Conventional Concrete (CVC). The volume of RCC is about 5.47 million cubic meters and that of CVC is 0.5 million cubic meters. The maximum production rate of concrete is approximately 16,000 cubic meters in 24 hours. The project period was about 5 years which was started on 2 November 1999 and ended on 30 October 2004. The total cost of the construction was 6,754,711,620.27 baht. The contractor is CCVK Joint Venture which consists of the China National Water Resources and Hydropower Engineering Corp., the China Electric Power Technology Import & Export Corp., Vichitbhan Construction Co. Ltd., and Krung Thon Engineers Co., Ltd. Vichitbhan and Krung Thon are the team leaders. The consultants are Asdecon Corp. Co. Ltd, Team Consulting Engineer Co. Ltd., and Coyne et Beller.

Khlong Tha Dan Dam was designed to have smooth upstream face with concrete facing and stepping downstream face. Based on the thermal analysis, RCC is designed to have vertical construction joints at every 40 m. The thickness of RCC after finishing compaction of each layer is 30 cm.

Figure 20: His Majesty the King Bhumipol went to laying the foundation stone at the main dam on 2 June 2001

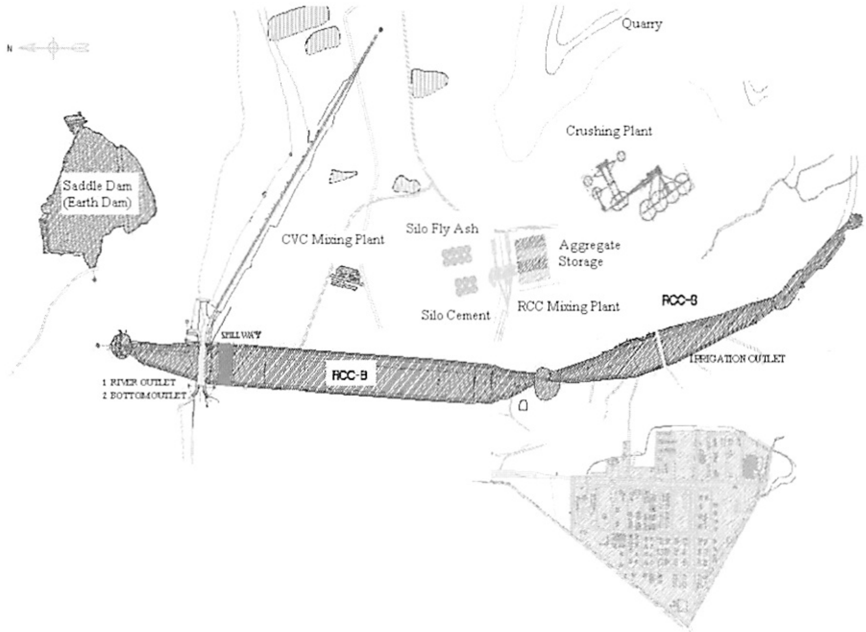


Figure 21: Project layout of Khlong Tha Dan Dam Project

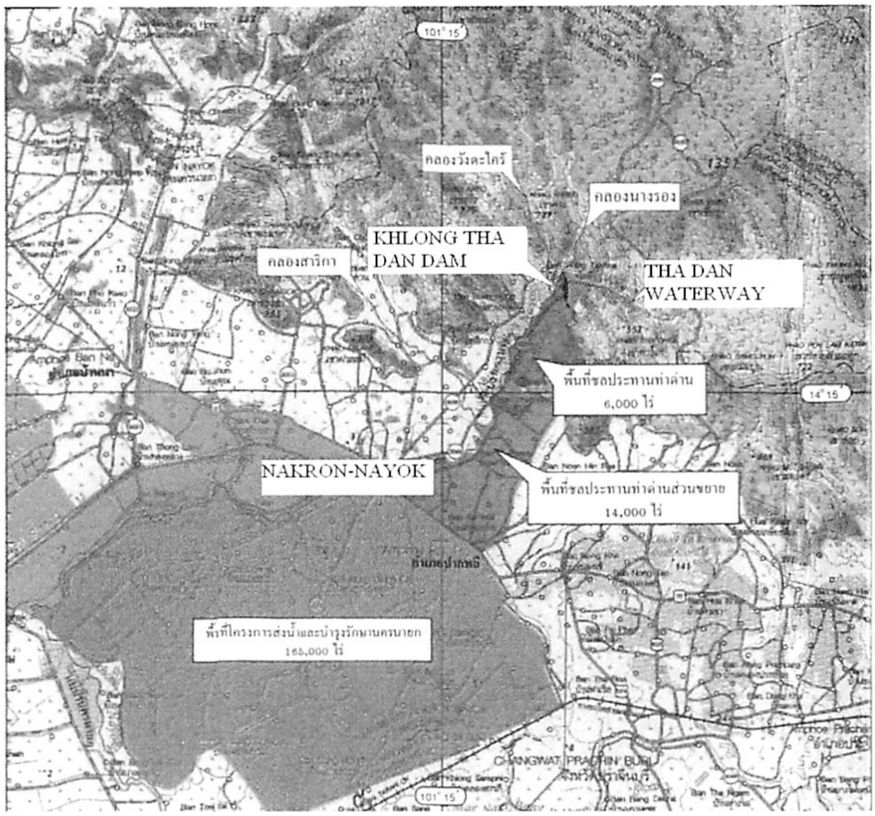


Figure 22: Location of Khlong Tha Dan Dam

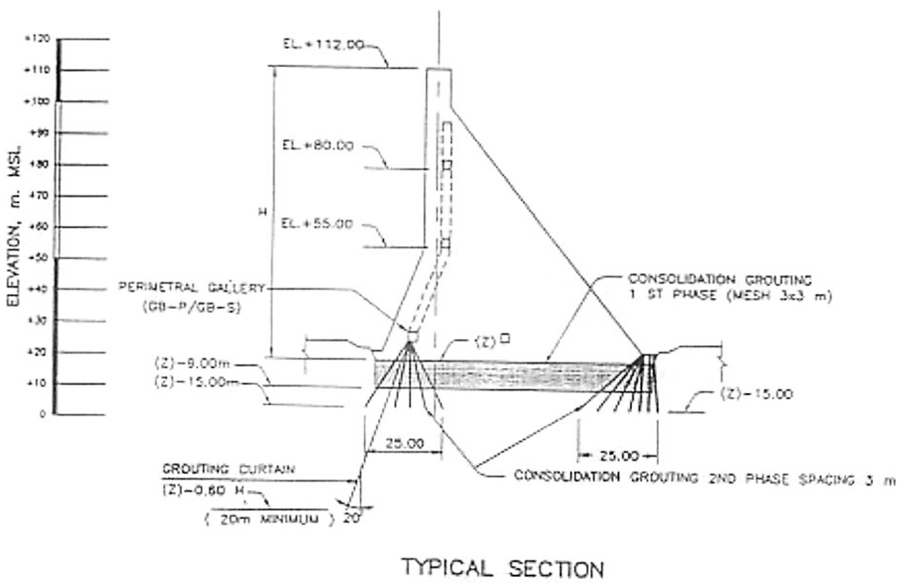


Figure 23: Typical section of Khlong Tha Dan Dam

9.2 Why Roller-Compacted Concrete (RCC) was Used?

RCC was selected as the main material of this gravity dam because of its economical advantages and the enabled efficient construction method.

RCC is widely used in many dams in the world for more than a few decades in Japan, China, America, etc. The concept of RCC is to compromising the advantages of concrete and earth dam construction techniques. If the conventional concrete (CVC) is applied, although the dam is able to gain high strength and high density but there is also high heat of hydration that may cause the serious thermal cracking problem. Besides, the material cost of conventional concrete dam is higher while the capability to work continuously is lower. On the other hand, when the earth dam construction technique is selected, dimension of dam is usually forced to be larger due to lower density of soil compared with that of concrete. However, earth dam construction enables continuous compaction work and, in some cases, costs cheaper. RCC dam is the efficient way to compromising merits of concrete dam and earth dam. It results in more economical and more efficient concrete dam construction. The advantages and disadvantages of these three dam construction techniques are compared in Table 9.

Table 9: Advantages and disadvantages of three dam construction techniques

Item	CVC dam	Earth dam	RCC dam
Strength	High	Acceptable	High
Heat of hydration	High	Not available	Low
Density	High	Low	High
Dam dimension	Small	Big	Small
Construction time	Long	Short	Short
Construction cost	High	Low	Low

9.3 Fly Ash as the Solution for Klong Tae Dan Dam

The basic concept of RCC trial mixing is to design the mix to meet the design criteria of strength, density, and workability. However, in the practice of RCC in Klong Tae Dan Dam, there are two major problems. First problem is that the poor shape of aggregate. (Actually, particle shape of aggregate is controlled by rock characteristics and crusher type) Irregular and flaky shape of coarse aggregate significantly affects the workability of RCC. The common solution is to increase paste content of RCC so that the workability meet required limit; however, this solution may cause more serious thermal cracking problem. The second one is the high plasticity of fine particles in fine aggregate. It was unfortunate that the fine particles contain materials, which have plastic properties as soil (low to medium plasticity index, PI), and it was not possible to remove these materials from fine aggregate. Concrete that contains higher amount of these plastic materials will have lower strength and higher shrinkage problem.

Two methods were selected to alleviate the problems. First, the fine content of crushed sand was reduced by modifying the crushing process. This solution produced coarse sand with lower find content, hence, reducing the effect of plastic materials. However, it also reduced the workability of RCC because of the lake of fine material to fill void among aggregates.

As workability problem became important problem at this stage, the second solution was processed by increasing the content of cementitious materials. Fly ash was then added to the mix for several advantages. The fly ash can be considered as reactive filler in the mix which will improve the workability of RCC. Second, although the relative amount of plastic material in fine aggregate is reduced but it still has effect on strength development, high amount of fly ash enable the reduction of water content and ensure long-term strength without any serious thermal cracking problem. The last merit of applying fly ash to the mix is to control cost of the binder rich mix. In the trial mixing, the target of design RCC mixture is to produce the mix that can reach the required compressive strength of 15 ksc at 90 days, sufficient density but have a little bit high Vebe time (The consistency and workability of RCC are measured by loaded Vebe apparatus in this construction project). It is thus clear that fly ash is the crucial material for making RCC with required strength, density, workability, and low cost in this situation. The final RCC mix proportion obtained from trial mixing is shown in Table 10.

Table 10: Applied RCC mix proportion

Item	Cement	Fly Ash	Water	Coarse Aggregate	Fine Aggregate
Weight (kg/m^3)	90	100	115	1431	674

9.4 Construction of Klong Tae Dan Dam

9.4.1 Foundation Preparation

Figure 24: Foundation excavation of the main dam

Figure 25: Rock foundation of the dam was clean and all weathering rock was removed before placing the leveling concrete

9.4.2 Raw Material Preparation and Storage

Figure 26: Storage area of aggregate before mixing

The aggregate was kept under the roof to prevent the heat from the sun in order to reduce the temperature of RCC.

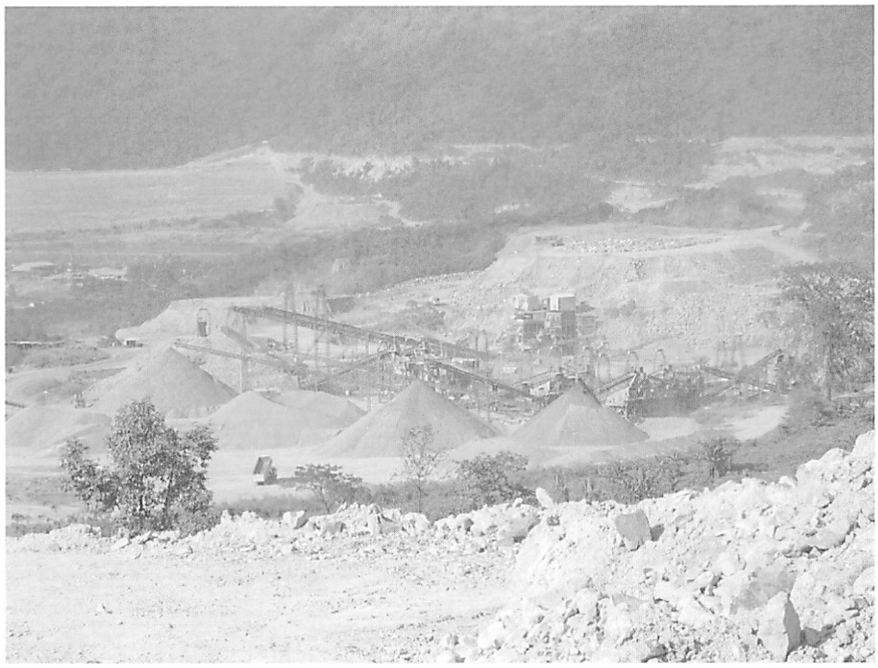


Figure 27: Crushing plant of aggregate

The crushing plant of aggregate used for producing RCC and CVC. It was locate in the reservoir area close to the quarry.

Figure 28: Storage silo for cement and fly ash

Silo for cement and fly ash has the capacity of 1,000 tons each. Six silos were used for cement and 8 silos were used for fly ash.

9.4.3 Mixing Facilities

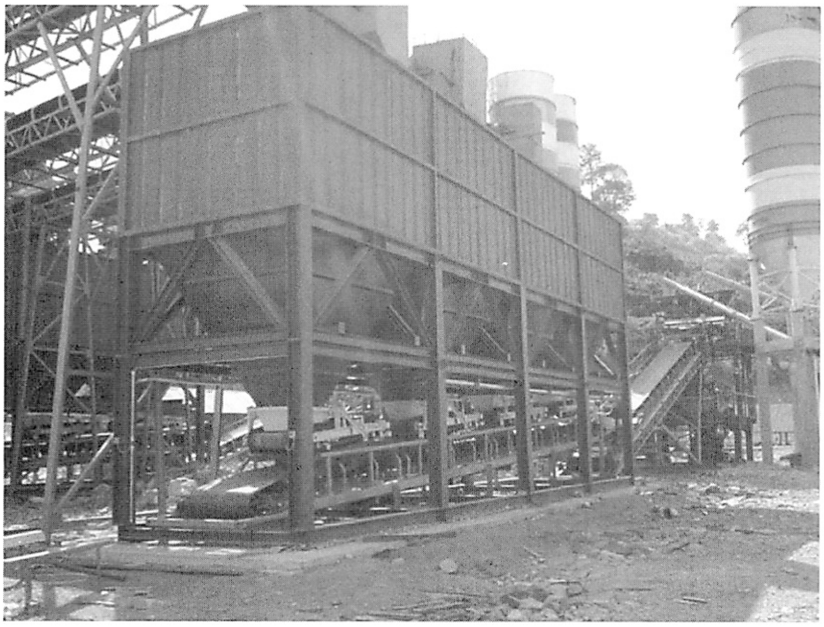


Figure 29: Mixing plant capable to continuously mix concrete

Two RCC continuous mixing plant were used for producing RCC. The mixing capacity for each plant was about 400 cubic meters per hour.

9.4.4 Concrete Transportation

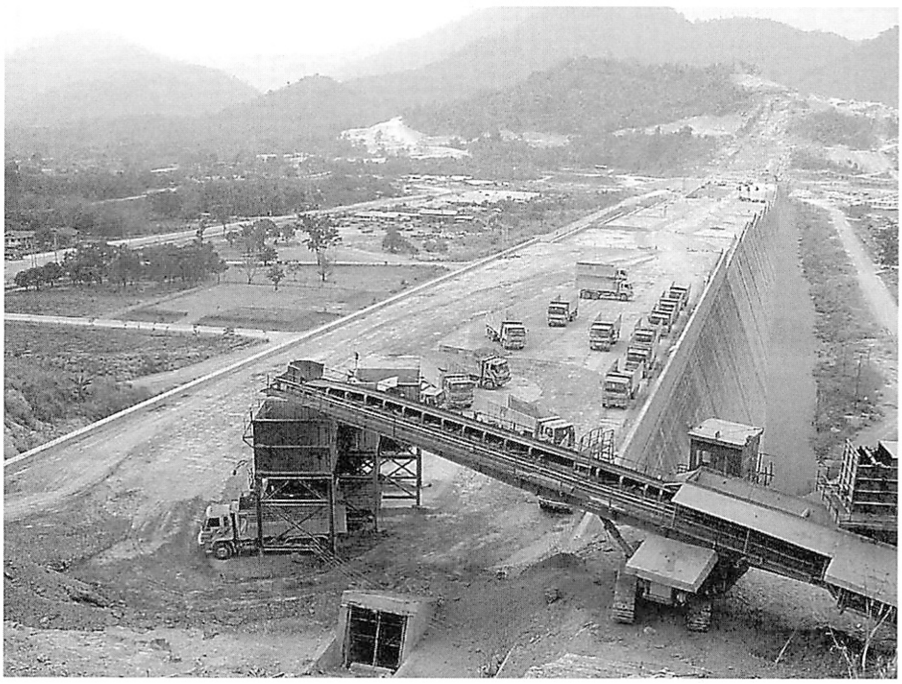
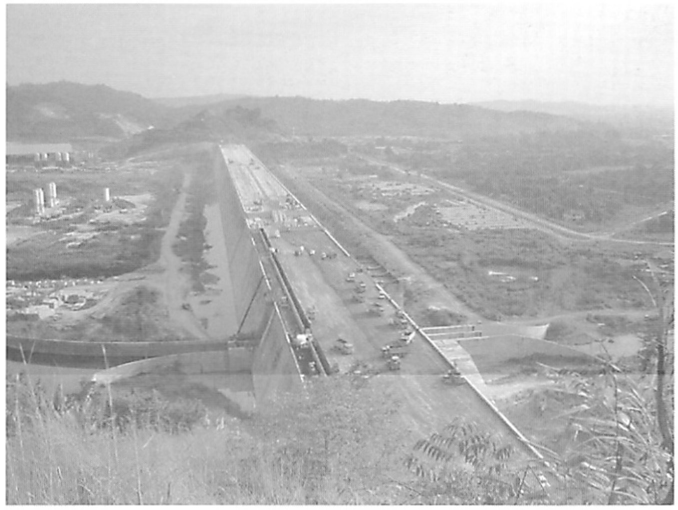


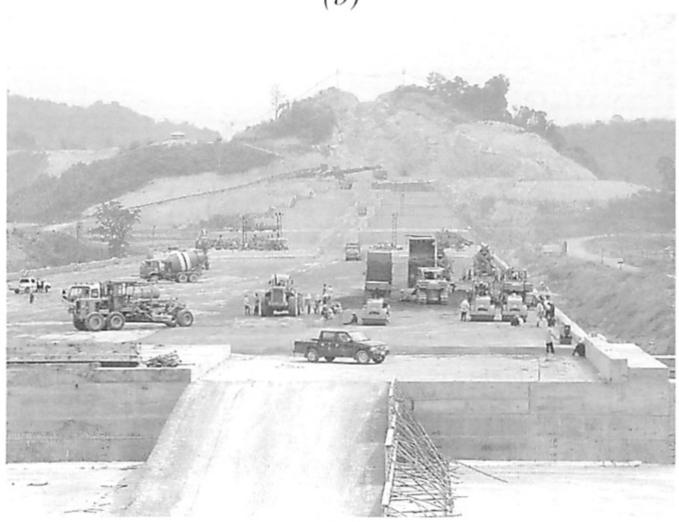
Figure 30: RCC was transported to the construction area by conveyer belt and trucks

9.4.5 RCC Construction Area



(a)

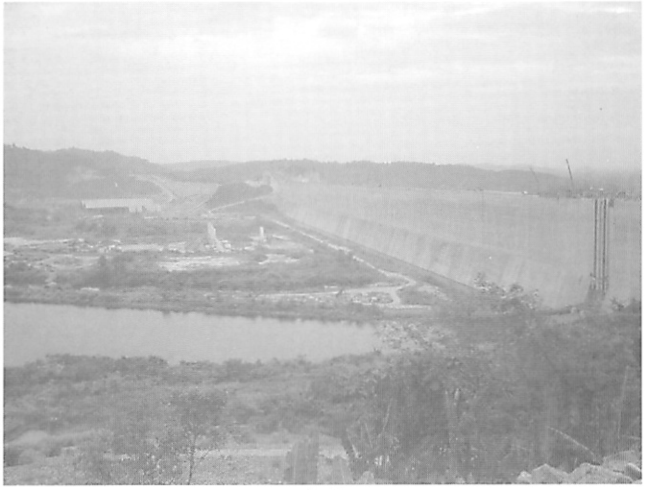
(b)



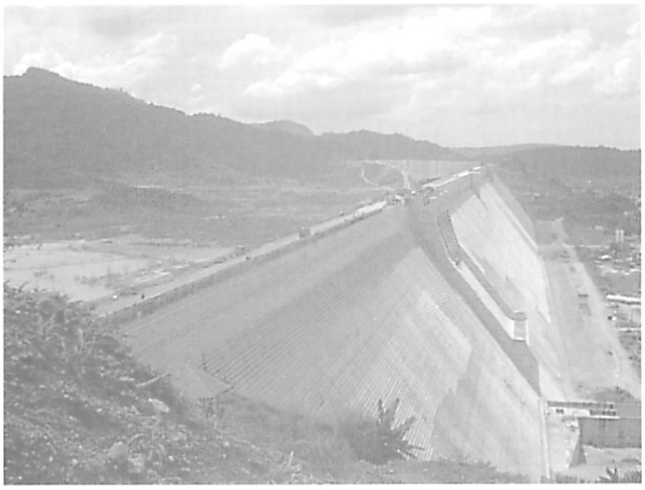
(c)

Figure 31: Construction area

9.4.6 Main Dam under Construction

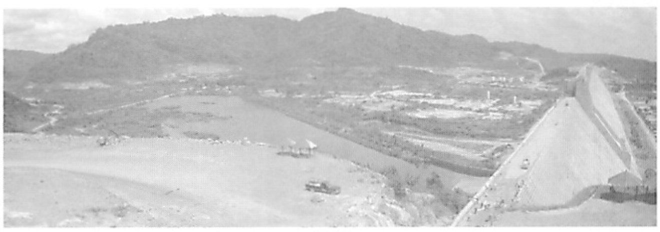


(a)



(b)

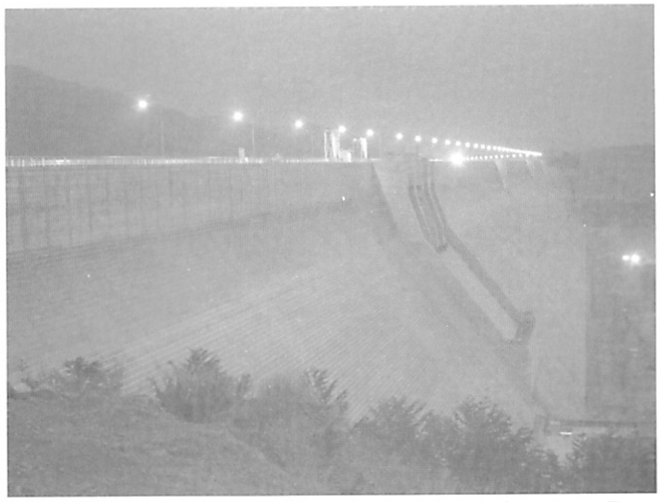
(c)



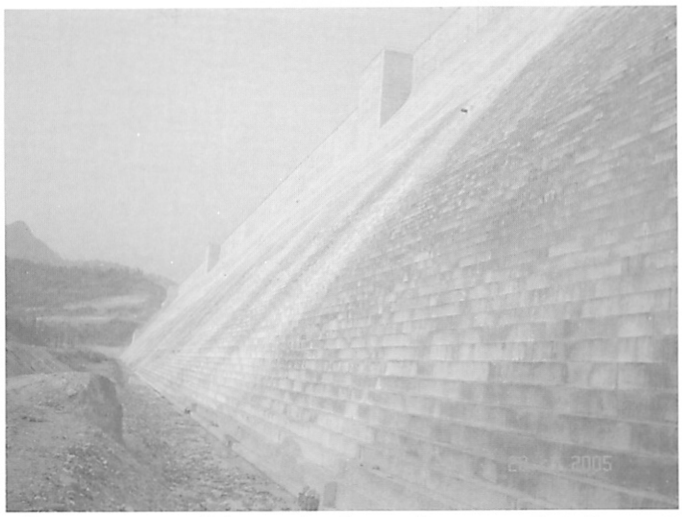
(d)

Figure 32: Main dam under construction

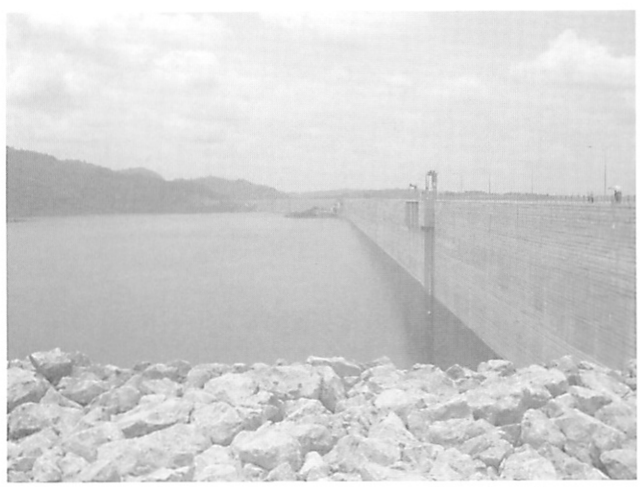
9.4.7 Completed Khlong Tha Dan Dam



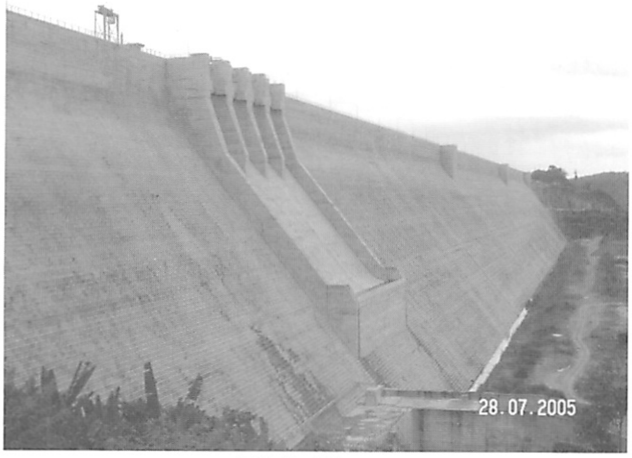
(a) Light up at the completed Khlong Tha Dan Dam



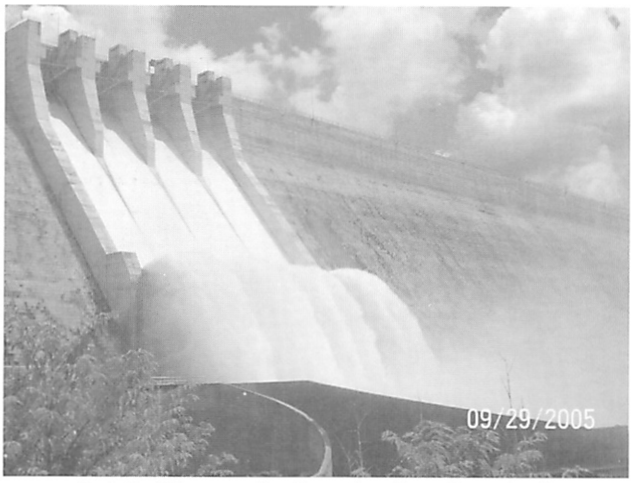
(b) The downstream of the main dam after completed construction.



(c) The dam after completed construction. The level of water was about +80 m msl.



(d) Spill way



(e) Spill way during the flood period.

Figure 33: Complete Khlong Tha Dan Dam

9.5 Quality Control Techniques of RCC in Khlong Tha Dan Dam Construction

Before start placing concrete in the dam, a full-scale trial section was conducted to collect many data for actual work such as suitable number of passes of the roller and suitable RCC moisture content. The training of all operators and placing inspectors were also done in the same period. The data obtained in the field are compared to the laboratory data. They were analyzed and adjusted for a better operation. The comparison of compressive strength of cylindrical specimens obtained by coring from trial section and laboratory samples is shown in Figure 31. Figure 32 shows the relationship between field density and number of passes of the roller. It was found that the appropriate number of passes of the roller were 6-8 passes.

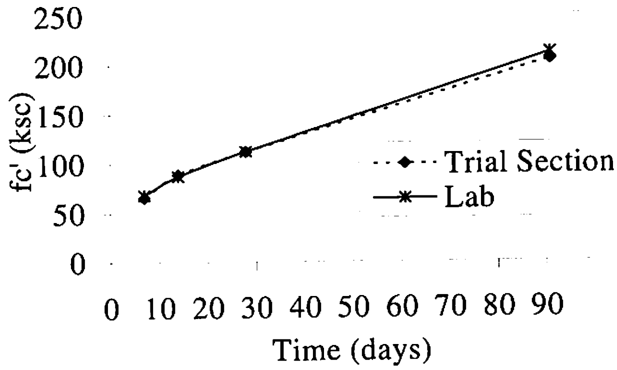


Figure 33: Compressive strength obtained by coring from trial section and in-lab specimens

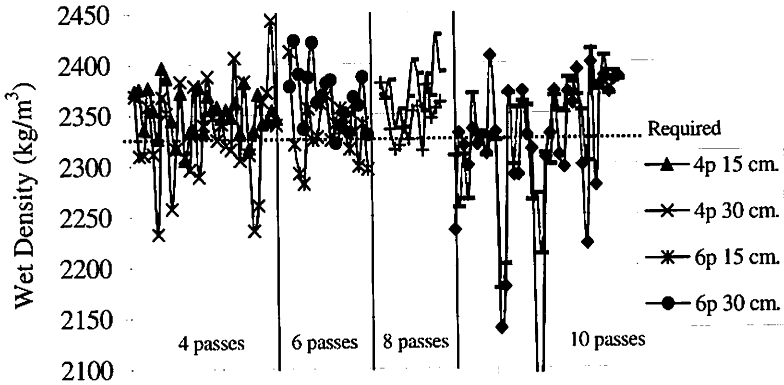


Figure 34: Relationship between field density and number of passes of the roller

9.5.1 Preparation before Placing.

All heavy equipments and operators are well prepared for operation. Steps of RCC work start from surface preparation. The paver machines are used to produce the concrete curb in both upstream and downstream faces. These curbs are used as formwork for both facing concrete and RCC. After finishing a few curbs, mortar, facing concrete and RCC are placed, respectively.

9.5.2 Horizontal Joint Preparation and Treatment

In order to increase bonding between the previous lift and the covered layer, the good joint preparation must be taken care closely. In general practice for all surface, which are less than 48 hours old, all deleterious materials such as uncompacted RCC, engine oil will be removed before placing the next lift of RCC. Surface will be cleaned by water, high-pressure air and mechanic brush. The surface will be cured and kept in moist condition. In contrary, the surfaces that are more than 48 hours old will be classified as cold joint. The mortar bedding will be placed on the cold joint surface. The thickness of bedding mortar will be 15 mm. For young surfaces on the upstream face, mortar is used for joint treatment and seepage control purposes too.

9.5.3 Mixing, Transporting and Placing

Normally, various types of mixing plant are used for RCC work. For Tha Dan Dam, two continuous mixing plants of the same type are selected with maximum capacity of 400 m^3/hr/plant. Cement and fly ash were weighed by load cells separately. For aggregate, each size of aggregate were weighed by belt scale and transported to the mixer by belt conveyors. All of cement, fly ash and aggregate will be measured in kg/sec while transporting. For water, the quantity will be measured by flow meter in liter/sec. Because the dam length is very long, RCC transportation system is the mixed system between high speed belt conveyor and truck system. After mixing all ingredients together, RCC will be transported to hoppers by high speed belt conveyors and then transported by trucks to the placing area. Bulldozers and graders were used for spreading and leveling respectively. Segregation problem must be carefully taken care of during transporting and placing. RCC will be compacted by double drum vibratory rollers. In the small area closed to formwork and upstream face where large rollers cannot work well, the smaller hand guided compaction machine is used to finish compaction in that area. The tamping foot type compactor is used in some area that hand guided compactor cannot work well. After finish compaction, RCC will be cured with water sprayed from water truck. RCC will be cured more than 7 days and if possible, it will be cured until 28 days. The maximum volume of RCC production in one day was more than 15,000 m^3. In one year, more than 1,500,000 m^3 of RCC are produced.

9.5.4 RCC Production and Quality Control

The rate of construction is very fast and the completed layer will be covered by the next layer every day but the test results will be obtained later so it is kept as historical data only. In reality, main attention is paid to the quality control for raw materials that are used for producing RCC and the process control is the quality assurance for RCC. RCC quality will be assured by controlling quality and proportion of raw materials, water content of aggregate and RCC during mixing and density of RCC in the field. If all of these data are in the control limit, it can be assured that RCC has good quality. The process of quality control is divided in to 3 categories, which are before mixing, during mixing and after mixing. The steps of quality control are shown in Figure 33. For easily memorizing, the test sequences were simplified to be tested monthly, weekly, daily, hourly and strength test. The frequency and purpose of tests for RCC quality control are shown in Table 11. Cracking due to hydration reaction is one of the important factors that must be considered in RCC. The principal factors that affect cracking are peak temperature of RCC, ambient temperature, modulus of elasticity and strain capacity or tensile strength. The volume change during heating up and cooling down stages and restraint of the change can lead to thermal cracking problem when the change exceeds its strain capacity. To reduce the peak temperature in RCC, the initial temperature is kept lower than 30 °C. Temperature of RCC is mainly controlled by the temperature of aggregates. Aggregates are kept in the stockpile under the roof to protect aggregates from absorbing heat from the sun. The temperature of aggregates in the pile is always around 25 to 28 °C. If temperature of aggregate is lower than 28 °C, RCC temperature will never be higher than 30 °C. In some situation while the ambient temperature is very high, chiller is used to cool mixing water. From thermal analysis, the dam is designed to have vertical construction joint every 40 m. The thickness of each layer of RCC after finish compaction is 30 cm. All test results in the lab will be recorded, analyzed and compared to the site test results obtained from the dam structure. Control charts of compressive strength, Vebe time and field wet density are shown in Figure 32 to 34, respectively. All data are plotted in the form of moving average for checking the consistency and quality of RCC. Not only the test result but also the trouble that happened in each section (RCC mixing plant, crushing plant and field work) was recorded for improving the construction speed.

Table 11: Frequency and purpose of tests for RCC quality control

Type of Test	Purpose of Test
Monthly	
Physical properties and chemical composition of cement and fly ash	Control/Record
Abrasion resistant of aggregate	Control/Record
Calibration of Mixing Plant	Control/Record
Gradation of aggregate from crushing plant	Control/Record
Calibration of nuclear density gauge by known density concrete block	Control/Record
Weekly	
Plasticity Index of fine particle in fine material	Control/Record
Check the accuracy of nuclear density gauge with sand cone test	Control/Record
Daily	
Wet sieve analysis of RCC	Control/Record
Gradation in each size of aggregate	Control/Record
Specific gravity and absorption of aggregate	Control/Record
Temperature of water and aggregate	Control/Record
Hourly	
Water content of aggregate and RCC	Control/Record
Temperature of RCC	Control/Record
Consistency of RCC, Vebe time	Control/Record
Moisture content of RCC	Control/Record
Sieve analysis of RCC	Record
Strength Test	
Compressive strength	Record
Splitting tensile strength	Record
Modulus of elasticity	Record
Compressive strength of cored samples from dam structure	Record
Field density	Control/Record
Permeability	Record

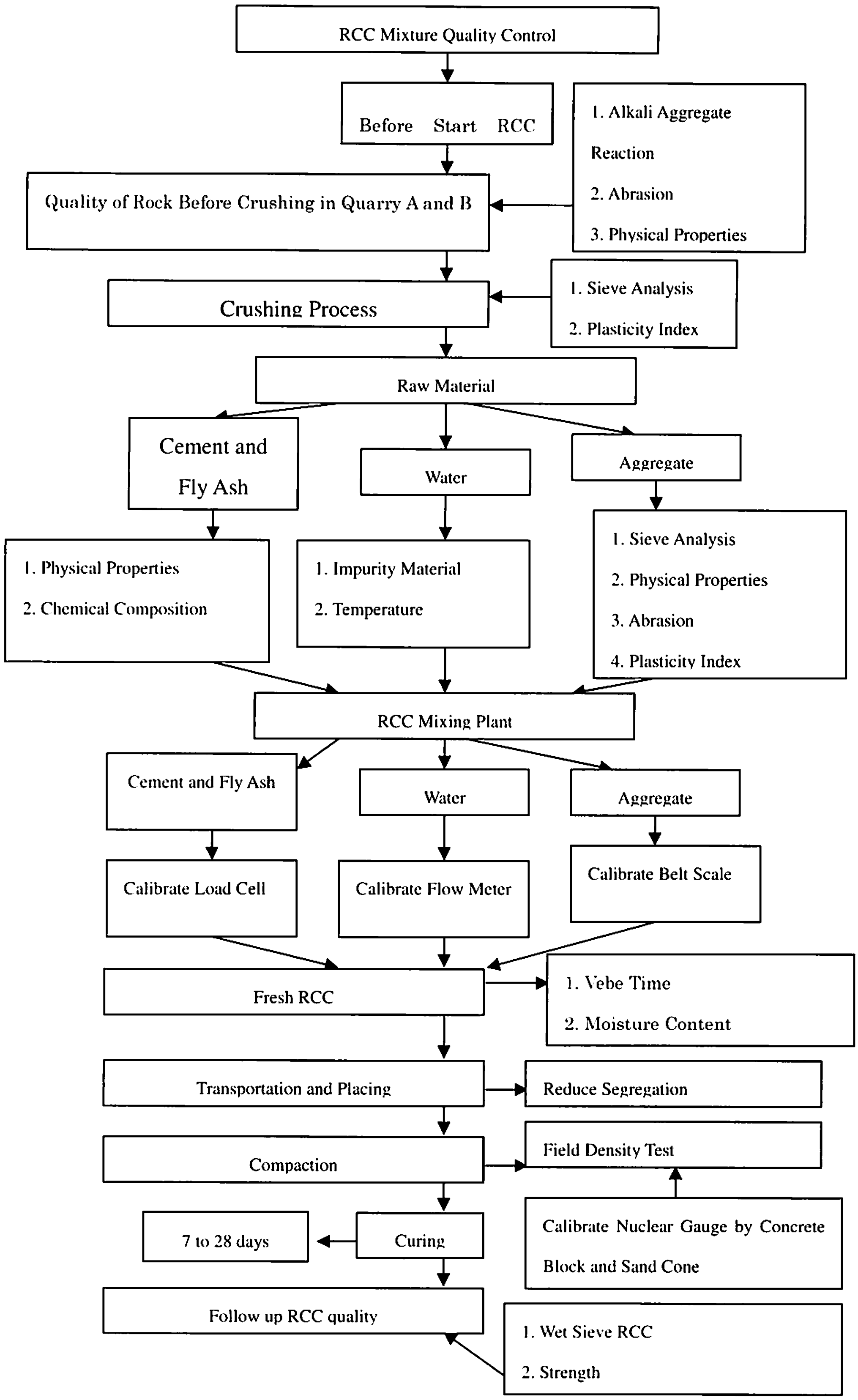


Figure 35: RCC quality control chart

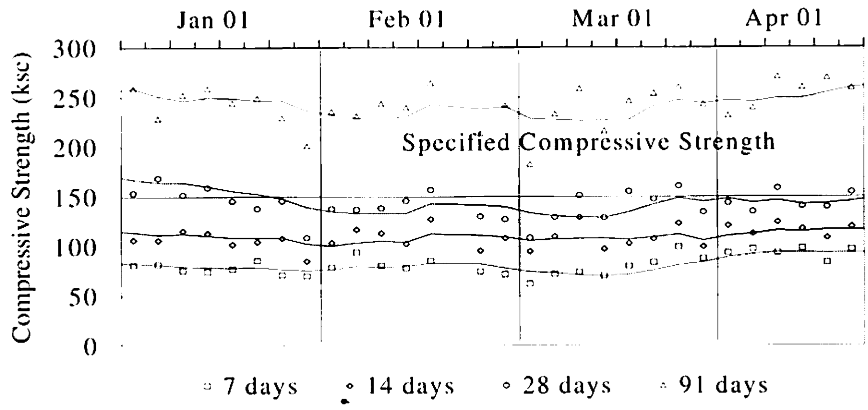


Figure 36: Moving average chart of compressive strength

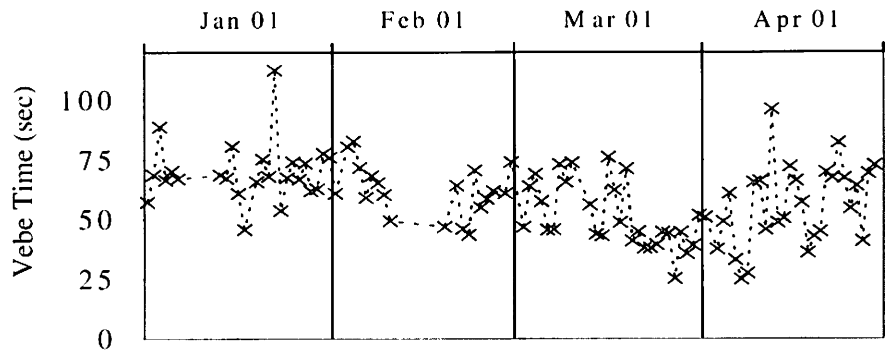


Figure 37: Moving average chart of Vebe time

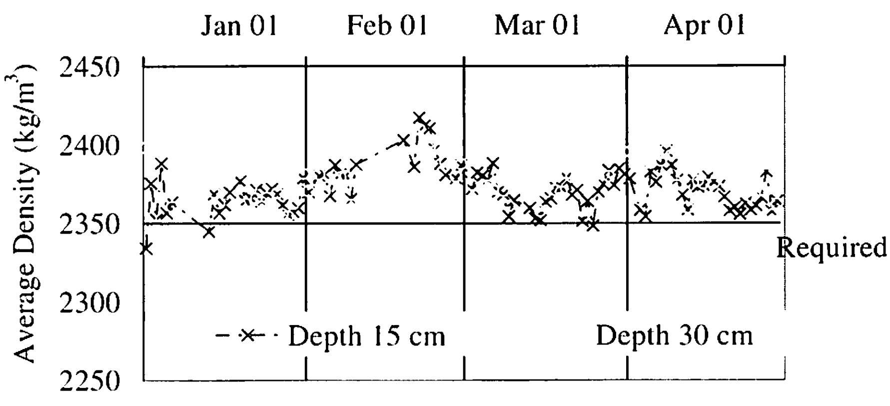


Figure 38: Moving average chart of field wet density

10. CONCLUDING REMARKS

This report summarizes the history and current situation of usage of fly ash in cement and concrete industry in Thailand and Japan. The comparison between the properties of Thai fly ash and Japanese fly ashes from various sources is firstly made as a basic investigation of the properties of concrete produced from these fly ashes and thus difference between Thai fly ash and Japanese fly ash.

The report explains subsequently the strategy and methodology to promote the usage of fly ash in Thailand. Based on what mentioned in this paper, it can be said that Thailand has become a very successful country in regard of fly ash usage in concrete industry. The success was obtained on great efforts and good strategic planning and patience of a number of academicians and professional engineers. The use of fly ash has also become one of the significant factors to change the concept of concrete practice in Thailand from that considering strength only to considering both strength and durability.

Then, the current situation of fly ash application in Japan is discussed. It is very clear that the situations in both countries are much different because of different resources, histories, and policy about energy and environmental reservation. Although the main usage of fly ash is likewise allocated in cement and concrete industry. Japan focuses the usage of fly ash as and ingredient for cement production while Thailand consumes almost all of its fly ash as the cement substituting additives.

Finally the case study of usage of fly ash concrete to solve the in-field problem of the construction of Khlong-Tha-Dan Dam – the biggest concrete dam in Thailand is also discussed. The section indicates the significance of good processing and testing and shows that effective usage of fly ash in concrete is not just relieve the environmental impact cause by electricity generation but can be certainly applied to solve construction problems by creating most suitable and economical concrete as well.

REFERENCES

1. RE Davis, RW Carlson, JW. Kelly, HE Davis, 1937, Properties of cements and concretes containing fly ash, Journal of American Concrete Institute, Vol.33, p.577-612.
2. US Bureau of Reclamation, http://www.usbr.gov/dataweb/dams/mt00565.htm
3. American concrete Institute, ACI 232.2R-96, 2000, Use of fly ash in concrete, In 2000 ACI Manual of Concrete Practice, Part 2, Michigan, ACI
4. Malholtra VM, and Ramezanianpour AA, 1994, Fly ash in concrete, Canada Centre for Mineral and Energy Technology (CANMET), 2nd edition
5. RILEM, 1991, Fly ash in concrete, properties and performance, Report of technical committee 67-FAB, Use of fly ash in building, editor Wesche, K., E&FN SPON.
6. Japan Society of Civil Engineering (JSCE), Committee on Energy, Techniques for Effective Usage of Coal Fly Ash, report (in Japanese).

7. P. Jirappapa et al, 1980, Study on the feasible usage of fly ash produced from Mae Moh Power Plant, Symposium on suitable technologies for rural development, Chiang Mai University, pp.195-205 (written in Thai)
8. P. Jirappapa et al, 1983, Concrete made from Mae Moh fly ash, Second seminar on technologies for rural development, Khonkaen University, 18-19 Feb 1983 (written in Thai)
9. P. Chindaprasirt et al, 1984, Study on Portland cement mixed with fly ash, 10th National science and technology conference, Chiang Mai, pp.536-537 (written in Thai)
10. P. Chindaprasirt et al, 1985, Portland cement mixed with Mae Moh fly ash, Rural Development Promotion Office, Khonkaen University, 58 pages report (written in Thai)
11. Technology Promotion Foundation under Royal Patronage, 2002, Development of usage of fly ash in Thailand, Book of Excellent Technologist Award of 2002, ISBN 974-229-369-4, pp.10-16 (written in Thai)
12. Electricity generating authority of Thailand (EGAT), 1993, Seminar on potential usage of lignite fly ash, R&D office, EGAT
13. Technology Promotion Foundation under Royal Patronage, 2002, Excellent Technologist Award of 2002, ISBN 974-229-369-4
14. P. Chindaprasirt et al, 2004, Influence of fly ash fineness on strength, drying shrinkage and sulfate resistance of blended cement mortar, Cement and Concrete Research, Vol. 34, pp. 1087-1092
15. K. Kiattikomol et al, 2001, A study of ground fly ashes with different fineness from various sourses as pozzolonic materials, Cement and Concrete Composites, Vol. 23, p. 335-43
16. J. Khunthongkaew, 2003, Vibrating consistency prediction model for roller compacted concrete, ACI Material Journal, Vol. 100(1), pp.3-13
17. Huang, J.Y., *Beneficial Use of Fly Ash,* Michigan Technological University
18. Sisomphon, K., Hongvinitkul, S., Nimityongskul, P., Tangtemsirikul, S. and Rachdawong, P., *Uses of Municipal Solid Waste Ash as Construction Materials*, Proceedings of the 7th East Asia-Pacific Conference on Structural Engineering & Construction, 27-29 August 1999, Kochi University of Technology, Kochi, Japan, pp. 1366-1371
19. Tangtermsirikul, S., Sudsangium, T. and Nimityongsakul, P., Class C Fly Ash as a Shrinkage Reducer for Cement Paste, Proceedings of the 5th CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, 4-9 June 1995, Milwaukee, Wiscosin, USA, Vol.1, pp.385-401
20. Tangtermsirikul, S. and Chatveera, B., Development of Low Heat Concrete using Lignite Fly Ash, Proceedings of the 4th International Conference on Civil Engineering, 6-8 November 1996, Manila, Philippines, pp.786-795
21. Tangtermsirikul, S. and Chatveera, B., Expansion of Cement Paste and Mortar using Lignite Fly Ash, Supplementary Papers of the 3rd CANMET/ACI International Symposium on Advances in Concrete Technology, 24-27 August 1997, Auckland, New Zealand, pp. 321-329
22. Tangtermsirikul, S., Kaewkhluab, T. and Jitvutikrai, P., A compressive strength model for roller-compacted concrete with fly ash, Magazine of Concrete Research, Vol.56, No.1, February 2004, pp. 35-44

23. Samranwanich, T. and Tangtermsirikul, S., A Model for Predicting Time Dependent Chloride Binding Capacity of Cement-Fly Ash Binder System, Materials and Structures, RILEM, Vol.37, No.270, July 2004, pp.387-396
24. Krammart, P and Tangtemsirikul, S., Expansion, Strength Reduction and Weight Loss of Fly Ash Concrete in Sulfate Solution, ASEAN Journal on Science and Technology for Development, Vol.21, Issue 4, December 2004, pp.373-390
25. Khunthongkeaw, J. and Tangtermsirikul, S., Model for Simulating Carbonation of Fly Ash Concrete, the 1st International Conference of Asian Concrete Federation, Chiang Mai, Thailand, 28-29 October 2004, pp. 907-917
26. Yamamoto, T. and Kanazu, T., *Accelerated Chemic al Assessing Method for Pozzolanic Activity of Fly Ash*, Abiko Research Laboratory Report No. U98047, Central Research Institute of Power Industry, Japan
27. Tangtermsirikul, S., *Mix Design of Fly Ash Concrete (in Thai)*, Engineering Institute of Thailand, November 1999, ISBN 974-382-909-9
28. Ashino, M., *Mix Design of Fly Ash Cement Concrete using Mae Moh Fly Ash*, M. Eng. Thesis No. ST-84-1, Asian Institute of Technology, April 1984
29. Chindapresert, P. and Horvichit, I., *Properties of Portland Cement mixed with Mae Moh Fly Ash*, Office of Technology for Rural Development, Faculty of Engineering, Khon Kaen University, 1985
30. http://flyash.learn.in.th
31. Committee on Concrete and Materials of Engineering Institute of Thailand, *Use of Fly Ash in Concrete*, October 2001, ISBN 974-7197-28-6
32. Committee on Concrete and Materials of Engineering Institute of Thailand, *Standard Specification for Materials and Construction of Concrete Structures*, 1st revision, 2003, ISBN 974-91685-4-2
33. Jakpisal, V. and Limsuwan, E., *Development of Shrinkage-Compensating Cement*, Proceedings of the 1st National Concrete Convention, Kanchanaburi, 14-16 May 2003, pp.23-27

APPENDIX A: PRICE OF MAE MOH FLY ASH

This Appendix shows the whole-sale record of fly ash produced from Mae Moh Power Generation Plant. Table 1 shows the data of amount of fly ash sale each year from 1999 to 2007. The customers are also classified based on their purchase volume. The price of fly ash climbed up almost 5 times during this period. This clearly indicates higher demand of fly ash in Thailand. It is also noticeable that there was no discount for high-volume sale until 2001. However, from 2002, customers who purchase more can gain a huge discount rate.

Table A1: Price of Mae Moh Fly Ash

	Number of Customers	**20**	**10**	**10**	**6**	**2**			
	From (Tons)	**-**	**10,001**	**50,001**	**100,001**	**200,001**	**Amount of Sale (Million Ton)**	**Average Price Baht/Ton**	**Total Income (x 1,000 Baht)**
	To (Tons)	**10,000**	**50,000**	**100,000**	**200,000**	**-**			
Year	**Initial Price (Retail Price)**	**Unit Price (baht/ton)**							
1999	65	65	65	65	65	65	0.6	65	39,000
2000	65	65	65	65	65	65	0.8	65	52,000
2001	70	70	70	70	70	70	1.2	70	84,000
2002	170	120	95	90	85	80	1.17	73.51	86,007
2003	170	120	95	90	85	80	1.5	93	128,960
2004	200	150	130	120	110	100	1.7	122	208,000
2005	250	170	150	140	130	120	2	139	278,000
2006	250	200	170	160	150	140	2	160	320,000
2007	300	250	200	180	170	160	2	185	370,000
Total									1,143,000

Source: EGAT, Thailand

INTERNATIONAL CENTER FOR URBAN SAFETY ENGINEERING
Institute of Industrial Science, The Universiy of Tokyo
4-6-1 Komaba, Meguro-ku,
Tokyo 153-8505, Japan
http://icus.iis.u-tokyo.ac.jp
E-mail: icus@iis.u-tokyo.ac.jp

Tel: (+81-3)5452-6472
Fax: (+81-3)5452-6476