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ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Prefabrication of Structural Elements:

A Case Study

By

Gutema Bulto W.

June 1998

Prefabrication of Structural Elements:

A Case Study

A Thesis

Submitted to the School of Graduate Studies

Addis Ababa University

In Partial Fulfillment of the Requirements for the

Degree Masters of Science in Structures

By Gutema Bulto W.

June 1998

ADDIS ABABA UNIVERSITY
Faculty of Technology



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December 4, 1998

U-55/91

TO: Prof. Theodros Solomon,
Dean, School of Graduate Studies

FROM: Mesfin Leikun (Dr.-Ing.),
Dean, Faculty of Technology

SUBJECT: Graduation of Ato Gutema Bulto



Ato Gutema Bulto has taken all courses required for M.Sc. Degree in Civil Engineering and has also successfully defended his Thesis. As regards CE 603 (Computer Programming) which is outstanding on his record, the Civil Engineering Department has recommended that the candidate be exempted from the course as he had taken CE 510 Computer Application in his senior undergraduate year.

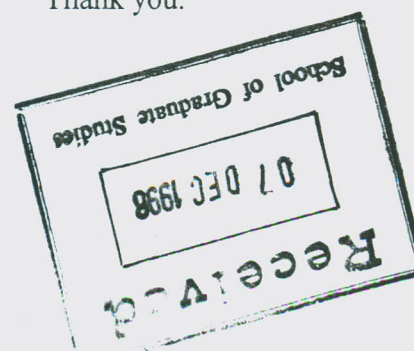
The Department confirms that CE510 combines both computer programming and application and treats computer programming in greater detail than CE 603 does. Further, the Department notes that CE603 was introduced as 1 cr. hr. in the graduate programme at a time when computer course was non-existent in the undergraduate programme of the Department. In fact the Department is currently in the process of taking steps to drop the course from its graduate programme.

In its meeting of November 27, 1998 (FGC/02/91) the FGC examined carefully Ato Gutema Bulto's case and decided to exempt him from taking CE603 as recommended by the Department.

This is, therefore, to request you to take the necessary steps to have his graduation approved by the University.

Thank you.

ML/kt
cc: Civil Engineering Department



Attn: Mr. Same
for CGS
S.S.
2/12/98

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SCHOOL OF GRADUATE STUDIES

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by

Gutema Bulto

FACULTY OF TECHNOLOGY

Department of Civil Engineering

APPROVED BY THE EXAMINING BOARD

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Chairman, Departmental Graduate Committee

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**Gutema Bulto W.
June 1998
Addis Ababa**

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ABSTRACT

The back-log of housing units in Ethiopia was so immense that all efforts made by the Government and inhabitants could not wipe out the shortage of housing in the early 1980s. To promote the building industry and to alleviate the housing shortage prefabrication technology was introduced. The Prefabricated Building Parts Production Enterprise (PBPPE), which makes use of IMS precast concrete system (a patent of the Institute for Testing Materials for prestressed concrete), was established in 1984 with a technical assistance from the former Yugoslavia. The objectives of the enterprise are to promote the building industry through mass production of precast concrete elements, to alleviate the shortage of housing and to reduce the construction cost. Since its foundation the enterprise has carried out the production of building parts and the erection of residential and public buildings. The IMS framework of precast concrete constitutes one of the widely applied industrialized building technology, because it provides for cost-effective mass production of buildings.

In the research work, a review of the experiences of other countries and a comprehensive literature survey on prefabrication was conducted. Then, the Ethiopian experience in the use of precast concrete especially the IMS system was assessed. The use and development of the IMS precast system were found slow and far below our expectation. To identify the sole cause that contributed to this effect, a sample survey was carried out and from the analysis of the survey conclusions were drawn.

After a thorough evaluation of the existing modules, to demonstrate the flexibility and the possible modification to the existing modules of the IMS system, a proposal was made for a G+1 dwelling building. Comparative analysis between the existing and the proposed modules was made and recommendations were forwarded. The study also considers the application of precast concrete to other special structures.

Finally, conclusions and recommendations were forwarded to promote the development of the IMS system. Essentially, great efforts should be done to disseminate technical information through brochures, manuals, design guidelines and advertisement to support the industrialization of the building industry in Ethiopia.

1.0 Introduction

1.1 Background

The backlog of housing in 1980 was estimated to 702,347 housing units to provide for new households and to replace dilapidated and obsolete units in Ethiopia, (MWUD,1983) but the volume of investment in housing receives a low priority. An increase in budget allocations for housing will not wipe out the shortage of housing because the building industry is unorganized and unable to meet even the current demands. Hence, traditional building methods must be rationalized and geared to mass production methods in factory thereby ensuring higher productivity, economy, speed of construction and assured quality.

The building process may be said to be better organized if, with the same expenditure, better or more buildings are built in a short time. A case for building by industrialized methods arises where there is a need for cutting down work on the building site as well as a demand for large quantities of the same and similar elements and where means are available to introduce mechanization and to establish the necessary factories for prefabrication.

Prefabrication may be in general terms defined as a continuity of production implying a steady flow of demands, standardization, integration of the different stages of the whole production process, a high degree of organization of work, mechanization to replace manual labor wherever possible, and research and experimentation integrated with production process (UN,1972).

Prefabrication is an age-old process, applied all over the world starting from different traditional prefabrication technologies up to modern concrete

precast elements. Recently, prefabrication system have returned to the attention of building experts as an option for large scale production of housing in developing countries as well as in the developed world.

In order to tackle the immense housing problems, third world countries started to use concrete prefabrication systems during the last decade (Stalen, 1994). For a while these heavy and large-scale systems became popular. However, because of its dependence too much on imported materials, equipment and know-how, the systems were not compatible with local indigenous building methods. At the same time the production of prefab elements was too centralized and the possibility for the users to participate in the construction process was limited. Due to these facts, prefab houses were unaffordable for low income groups, which eventually caused the prefabrication process to have a slow progress. But this does not illustrate the malfunctioning of the principle of prefabrication by itself. What matters is an appropriate system and its adequate application.

The prefabrication technology was introduced in Ethiopia in an integrated manner in 1984. The establishment of Prefab Housing Factory in Addis Ababa has brought new techniques for the construction industry and it was supposed to cater the solution for the vast building needs. The aim was to accommodate the ever increasing demands of housing within the shortest possible time, to overcome the shortage of accommodation and meet the future demands, and to minimize the pressing need of timber for formwork and consequently conserve the natural forest.

The Factory primarily in charge of prefabrication - Prefabricated Building Parts Production Enterprise (PBPPE) - has produced structural elements for the construction of office buildings, apartments, hotels and residential buildings over the last ten years for the public and private sector. The theoretical design

capacity of the enterprise was estimated to reach 50,000 m² of built-up floor area per year, but the maximum attained capacity to date is 33,000 m².

The production output of the enterprise was designed to build three categories of buildings: the residential buildings up to 5-storeys, residential buildings up to 10-storeys and public buildings up to 10 storeys. The types of structural elements produced by the factory are over 38 which includes various types of columns, slabs, footings, girders, shear walls, stair flights and landings.

1.2 Statement of the problem

The prefabrication industry was introduced in Ethiopia with an intention of using new methods and techniques of construction and the industrialization of housing construction, there by overcoming the shortage of housing, improving the low productivity of construction labor and improving the working conditions. But, the activities of the enterprise are far behind the expectation because its production was limited to certain modules without adequate variety of elements. The utilization of the existing designs and modules without further improvement has handicapped its further development. This may has restricted the existence of flexible and sound designs which subsequently limited the use and development of precasting. In addition, the few number of frequently used sizes might have also retarded the promotion of prefabrication. Resorting to a variety of modular coordination and standardization, a number of advantages such as saving in construction time, reduction in wastage volume, saving in labor and mass production can be achieved.

In Ethiopia, there is a need of standard code that caters for an integrated use of precast concrete with the traditional cast-in-situ concrete. Such standard should include design techniques of dimensional coordination, adoption of preferred sizes and their adaptability in order to achieve the full benefits of prefabrication.

means for mass production of varied modular coordination of elements.

4. To suggest modules of preferred and frequently used concrete elements in addition to the already existing structural elements.
5. To investigate the possible utilization of precast concrete for other civil engineering work such as culverts, bridges etc.

1.4 Methods of the study

The research approach would be the identification of critical bottle necks in the design, production and erection of prefabricated structural elements. To this end a comprehensive literature review was carried out. Pertinent journal articles, manuscripts, working papers and reference books related to the subject area are referred. Relevant technical documents, drawings, bill of quantities, project reports, correspondences available at the Prefabricated Building Parts Production Enterprise and other organizations were evaluated. In addition, an interview with senior technical and management personnel of the enterprise was conducted.

Furthermore, a comprehensive sample survey was conducted and primary information was collected on the development and use of precast concrete in Ethiopia. The practices in precast concrete production of structural elements in Ethiopia were examined to figure out the importance of the experiences gained in the past. Finally, based on the experiences gained, the assessment of the existing situation and incorporating professional opinions from the survey, conclusions and recommendations were forwarded in order to promote the development and use of the precast technology in the future.

A proposal was made to include additional prefabricated elements possibly needed by the public to be included to the existing precast concrete stock as a demonstration of the various design solutions. Also an assessment was done in order to see the degree of the utilization of the prefabrication technology for other civil engineering works.

1.5 Organization of the Thesis

The thesis is organized into seven chapters. The first chapter is the introduction which contains the statement of the problem, objective and the methods of approach. The second chapter discusses the experiences gained so far in prefabrication in other countries followed by the third chapter which explores the Ethiopian experience in precast concrete. It investigates the reasons behind its slow development in the building industry. Chapter four presents the basic principles of the IMS prefabricated skeleton system adopted in Ethiopia. The fifth chapter examines the prospects for the growth of precasting, and investigates the possible utilization of IMS system for low rise buildings. Additional sections were proposed where the possible standardization in prefabrication of structural elements, structural design and comparative analysis of different sections were carried out. The sixth chapter deals with the application of prefabricated concrete elements for other special civil engineering works. Finally the last chapter presents the conclusions and the recommendations of the findings.

2.0 Prefabrication of structural Elements

2.1 The Precast Concrete

Prefabrication system, also commonly known as prefab system, has gained the attention of housing experts as an option for low-cost housing. There exist different traditional prefabrication technologies applied all over the world, mainly in developing countries. These include prefabricated moveable thatched roofs in Ethiopia, Vietnam and Mexico, bamboo panels in Latin America and Asian architecture and the prefabricated timber elements. Such prefabrication technologies are mostly encountered in informal and unauthorized housing areas.

The use of bamboo panels has certain advantages. First, transportation costs are negligible, because of the wide availability and on-site production of the panels. Second, the input of professionals is reduced considerably as a result of participation of users, especially during the assembly and finishing. As a result, savings are made in terms of construction time and in the total housing costs.

Non-reinforced concrete blocks produced in molds and used for wall material in Colombia and the prefabricated hollow core panels which are integrated in self help housing projects in China can be mentioned to show some of the uses of prefabrication. Among the various prefabrication systems, wooden prefab houses, light gauge steel prefabricated systems, light weight concrete blocks are in use as well as the precast concrete systems.

The term precast concrete is used to describe products of concrete made under factory conditions in a permanent premises or in temporary casting yard on construction site where it would be erected as a building system. The

various uses of precast concrete in the field of building industry in addition to the structural elements include non structural elements such as curbs, paving slabs and those having minor structural nature such as lintels, lamp posts and pipes. Small complete buildings that can serve as shelters (bus terminals, garages) can be made quickly and cheaply when made with prefabricated cladding materials in combination with conventional concreting system.

At present, many standard precast elements are available in developed countries and the engineer should make himself aware of the existing products before deciding to use his own design. After a proper review of the existing products, one may choose a particular standard product as a solution to a structural problem. The precast concrete chosen for a particular solution may be used advantageously in conjunction with in-situ-concrete for better performance. Thus, the Engineer must familiarize himself with the range of available elements, consulting published information on matters of depth, span and other properties alike.

The use of precast concrete members by the construction industry has increased rapidly throughout the world over the past two decades. Advantages such as speed of erection, better quality, dimensional precision and above all, reduction of cost have made precast concrete superior to the cast-in-situ concrete. The satisfactory performance of a precast structure as a whole, and its economy, depend to a great extent on the proper selection of appropriate range of elements available and its connections.

Precasting avoids the traditional restraints inherent with in-situ work such as formwork erection, steel fixing, concreting and service installation. It allows to remove the risk of delay in any of the critical activities that completely hinder the progress of construction works (Richardson, 1983)

The advantages of precast concrete over the cast-in-situ concrete are listed as follows (Hartland,1975)

1. Construction takes shorter time and the investor will be able to use the building for the intended purpose in a shorter time.
2. Reduction in cost of formworks, scaffolding and temporary supports can be achieved. For instance, 1m^3 of monolithic concrete requires approximately 0.12 to 0.15 m^3 wood for formwork and scaffolding, while 1m^3 precast concrete requires not more than 0.01 m^3 of wood (Krimsky, 1958).
3. Reduced amount of wet work on site which reduces the demand of local site labor.
4. Adverse weather conditions do not affect the construction of precast system.
5. Precise molds could be used for the mass production of units and these molds could be re-used for a considerable repetitions.
6. Due to the use of trained and specialized personnel working under factory conditions, good and standard units can be produced. Thinner and more efficient shaped members could be produced.
7. Sub-standard products can be inspected and rejected before the erection of the system.
8. Conduits for other services can be incorporated into the units during production of the units.
9. Different shapes and finishes may be achieved after a long experience of using variety of materials.
10. Extension of structures or if required, the dismantling of certain structure and re-erect else where is possible.
11. It offers better fire protection and requires little maintenance.

Specifically, the IMS system precast concrete construction do have considerable saving in material and labor. The indices of material and manpower input in the IMS framework construction per m^2 total area for 4.20x4.20m span is 0.1374 m^3 concrete, 10.33kg reinforcement, 1.4kg prestressing steel and a total of 3.06 hours for manpower involvement in production, assembly, and cable tensioning. The cost indices per m^2 of apartment space indicate 45% of material, and 35% of labor saving compared to the conventional building construction system. Totally, a cost saving of 25% can be achieved using the IMS system (Milos,1982).

However, on the other hand, the shortcomings of precast as compared to the cast-in-situ concrete can be summarized as follows (Hartland, 1975).

1. The high quality units produced at factory always pose the greatest problem at joints between the members.
2. Last minute changes cannot be accommodated once the units are cast, therefore a high standard of design, detailing and checking is required.
3. The units require some additional reinforcements for handling, transporting and erection as well as for stress conditions pertaining to the same.
4. Large size units may require considerable storage area, transportation and erection costs.
5. Precasting is economical only for regular feature buildings and for molds with high degree of repetition.
6. The lifting capacity and range of cranes available govern the size and weight of the precast units.

2.2 Experiences in precast Concrete

Prefabrication is the process of manufacturing of standardized products of components prior to assembly on the site essentially to mechanize the traditional site operations. It constitutes part of the industrialization of the building sector in order to solve the ever increasing demands for housing. When considering the industrialization of building one has to take into account those factors such as the availability of abundant and cheap labor, the large demands for housing and suitable mechanical equipment.

There are various materials used for prefabrication in the building industry out of which the precasting of concrete elements constitutes the major building material. In this study attention is given to precast concrete elements because most structural building units are made from concrete. To this effect, first the assessment of the experiences of other countries is presented.

2.2.1 The Russian Experience

In the prewar years, precast concrete members were manufactured by the most primitive methods mainly at the building sites with few specialized and well equipped factories. So the production was focused on the production of heavy members at the place of installation and the members were produced at casting yards using wooden molds and formworks. The manufactured members were cured in the open air. The erection of the precast members was carried out with the aid of booms, derricks, tower cranes and crawler cranes, which were not sufficiently provided for all building sites.

The advantages of precast concrete over monolithic concrete and metal structures have led to its popular use in the Soviet Union. The growth in the production of precast concrete was coupled by the growth of enterprises

engaged in the manufacture of these products and the improvement of the production technology. Precast concrete technology was introduced in the former Soviet Union in the late 1920's, but it found especially wide application between 1930-1936, mainly for industrial constructions and for the erection of single-storey buildings (Krimsky, 1958). The most interesting building structures built with precast concrete members witness the scope of its application at that time. In 1950 and 1955 the volume of precast concrete equaled 1,290,000m³ and 5,260,000m³ respectively. In fact the precast members were combined with monolithic reinforced concrete, wooden and sometimes steel structures in the same construction project.

Buildings erected with precast concrete in Russia from 1925 to 1940 are so many out of which it is worth mentioning one -storey industrial buildings, a number of 3-5 storey production blocks, etc. The precast concrete has been in use for a long time mainly for the construction of single-storey industrial buildings, but was not employed for residential buildings until recent years.

The assortment of precast concrete products was considerable and it comprised of the following structural elements (Krimsky, 1958)

- rectangular columns, with length reaching upto 15m,
- Roof beams rectangular, T-, I- and box sections upto 10m. length,
- Crane runways, continuous simple beams with spans of 6m.
- One storey single-span frames made up of one member or composite (comprising columns and girders)
- Roof trusses with 15 to 22m spans and arches with 27.5m spans
- Small span slabs (solid and ribbed) and stair ways and landings.

2.2.2 The Jordanian Experience

Precast concrete construction technology was introduced in Jordan for the first time in the 1980's by a foreign construction company in the construction of the airport. The Jordan Precast Airport construction was the largest project ever undertaken in that country. A new technology - precast concrete - was introduced into the kingdom. The project cost was \$350 million US dollars. The three factors that dominated the design consideration of the project -Queen Alia International Air port of Jordan - were expansion of the existing facility, security and earth-quake resistance.

The precast structural elements used include beams, girders, and other elements. The architects and structural designers limited variations in span length and standardized the dimensions of the structural elements. Most beams were 1m deep, 35cm wide and 9m in length. The critical elements of the design were earthquake resistance and the design of transferring loads between the precast and the in-situ column structures. Extreme care was taken in sizing and locating rebars, lapping length and connections.

The use of precast concrete solved several problems of the construction industry of the country. The need to transport skilled workers to the site was limited. Quality control was easier at the plant which would have been hard on site with the available local unskilled labor force. Construction speed was necessary because of the high temperature with high evaporation rates where water was a precious commodity. Good sand, aggregate and labor for such large project in a relatively small country was scarce. Workers were recruited from Europe and Asia to complement the local work force.

The modular design at Queen Alia Airport will permit further expansion of the airport capacity without disrupting the existing operations. The use of precast concrete technology has allowed to solve the construction problems at the project implementation phase of the project.

2.2.3 The Japanese Experience

In 1966 the Ministry of Construction of Japan announced "Fundamental idea on Industrialization of Housing Building" and "Promotion of 4 to 5 storey department houses" with the aim of popularizing industrialization of housing, stabilizing building costs and improving the quality of houses. Machines and equipment to manufacture building parts were introduced to enhance prefabricated construction. The prefabrication introduced consisted of wooden frame structures, precast concrete structures and light-gauge steel prefabricated systems.

To mechanize the industry the Government provided loans to contractors to buy machines and enacted law to promote the industrialization process. Building codes were introduced to regulate structures, capacity and application for building permits. In 1964 a series of a National standards relating to modular coordination was finalized. To standardize the designs and specifications of parts and accessories for public housing, to improve the quality and to reduce the production cost; standardized parts were introduced. Great efforts were made in the improvement that in 1962 the development of mass produced houses was so appreciable. Four to five storeyed houses were built using big precast concrete panels, that can resist earthquake forces. In the same year 800 houses were built, 5000 in the following year, and 12,000 units in 1964 (UN, 1972,p 91).

Prefabrication, especially precast concrete construction has brought great advantage in the development of industrialization and mechanization of the building industry in Japan.

2.2.4 The Singapore Experience

Precast concrete was adopted as a solution of choice for up grading Public Housing in Singapore. The Housing and Development Board (HDB), the sole public housing Authority and responsible for providing high quality houses at affordable prices in Singapore, has launched a program to upgrade the quality of the existing stock of public housing. Since its inception the HDB is credited with constructing more than 750,000 apartments for housing 86 per cent of Singapore's population (Ming, 1976). Prefabrication technology was used to overcome the many difficulties associated with the construction of high rise apartment extensions in heavily populated areas. The use of precast concrete elements helped to over-come the special difficulties of construction work in the congested areas. The upgrading mainly consists of a newly added space stack which is designed to be completely on new independent foundation.

The technology and construction methods chosen in the upgrading program meet the basic requirements such as 1) enhanced safety and security where there is control on the noise and dust pollution arising from the construction site 2) it is a dry construction process that result in faster construction time 3) cost effectiveness responds to the budgetary constraints. The extensive use of prefabrication methods that hinge around offsite/on-line factory production techniques of building components fit the requirements. At the same time, prefabrication ensured better standards of construction workmanship and reduced the need for skilled foreign labor.

The implementation of the program started in 1991 and 21,000 housing units have been upgraded by 1994 in three phases. The validity of the use of prefabrication in public housing upgrading hinges on ensuring that the component designs are kept simple and streamlined; standardization of precast

concrete components is imperative; there must be an optimum number of repetitions of components; the size and weight of the components must be kept to the minimum (Ming, 1996).

The standardization and the repetition of components go with the architects requirements for aesthetics and flexibility of design. In the highly built up nature of the existing sites it would have been difficult if not impossible to construct using conventional cast-in-place methods.

The cost of construction of the added space was found to be 4 times less than the construction cost of a new block of apartments with conventional cast-in-place methods. The lower cost of construction, the shorter time of construction, the non-existence of noise and dust pollution have contributed to the success of the program showing the importance of precast concrete.

2.2.5 The New Zealand Experience

Since the early 1960s, the use of precast concrete in New Zealand for floors, moment resisting frames and structural walls of buildings has been steadily increasing. Precast concrete has been chosen for its advantages of high quality control, reduction in site formwork and site labor and increased speed of construction. In particular, with high interest rates and pressures for new building space in the mid 1980s, the speed of construction gave precast concrete a distinct cost advantage in New Zealand. (Park, 1995).

The ever increasing use of precast concrete required considerable innovation against the active seismic hazards in New Zealand, a country located in an active seismic zone. By the time, the New Zealand concrete design standard contained comprehensive provisions for the seismic design of cast-in-place concrete structures, but it did not have seismic provisions covering all aspects of precast concrete structures. Therefore, new design

methods were introduced in the 1980s for frames of buildings incorporating precast concrete elements. This brought confidence in the use of precast concrete in moment resisting frames with a general aim to achieve behavior equivalent to that of a completely cast-in-place concrete structure.

In line with the increased use of precast concrete for seismic resistance, it was demanded to carry out more research and testing to justify confidence in the structural systems. For this purpose in 1988 a seminar attended by concerned stakeholders (designers, researchers, fabricators, and constructors) was held in the University of Canterbury. The objectives of the seminar were 1) summarize data on precast concrete design and construction 2) Identify special concerns 3) Indicate recommended practices and 4) to recommend topics requiring further research. (Park, 1995).

The outcome of the deliberations was the publication of a manual "Guidelines for the use of structural precast concrete in buildings" which was first printed in 1991. The guideline contains provisions for the seismic design of structures incorporating precast concrete. From then onwards, precast concrete was used reliably and widely. The elements for moment resisting frames, and the structural arrangements can be divided into three systems which are precast reinforced beam elements spanning between columns, precast reinforced concrete elements passing through columns, and T-shaped and cross-shaped precast reinforced concrete elements. Structural continuity between precast concrete elements is generally achieved using cast-in-place reinforced concrete.

During the boom years of building construction in New Zealand in the mid and late 1980s parallel to the industrialization of the building industry, improvement of the precast concrete in technical terms was achieved.

2.2.6 The European Experience

Extensive development of the precast concrete industry has taken place in Europe following the Second World War as a result of specific, social and economic conditions at that time. Systems building in Europe was spurred as a result of housing shortage following the war. The reasons behind the shortage of housing was the destruction of the housing stock by bombing, and the fact that housing construction had been interrupted for the major portion of the war years, increasing numbers of new households and a large degree of resettlement and relocation. Not only the physical shortage of housing, but also shortage of skilled labor in construction industry has coupled the problem leading more towards systems building, especially precast concrete construction.

Precast concrete construction required fewer skilled workers than the traditional construction, and also significantly reduce the required time for construction of housing. In addition to the wide spread shortage of lumber and structural steel across Europe for formwork precast construction of housing stood as the exclusive choice of the time.

The main factors that contributed to the success of precast concrete systems in Europe can be attributed to the intervention in the housing market on the part of the governments. Governments especially in Eastern European countries, where government controls over the construction industry and the land market, have realized the incredible need for housing, and have extensively funded numerous programs. For instance in Russia between 1950 and 1968 housing was provided for almost 120 million people the majority of this housing being precast concrete systems. As quoted by Sullivan, in 1953 in France, the government through the Ministry of Housing sponsored a large scale precast concrete housing project for over 4,000 units (Sullivan, 1980). By formulating favorable policies and sponsoring large-scale housing projects governments in Europe aided and encouraged the development of precast concrete construction.

2.2.7 The American Experience

Initially, in North America, the housing industry was fragmented and substantially diluted having more regional nature than in many European countries. Nevertheless, as a result of precast concrete systems successful application in Europe, a great deal of interest was generated in the 1960s (Sullivan, 1980). With the involvement of large precast companies of Europe who were interested to expand their markets, many different systems were introduced in the United States and Canada, but very few were successful in precast housing. The reasons behind this was 1) high costs of the systems relative to the existing traditional housing construction 2) initial capital costs could not be justified 3) inadequate feasibility study and incorrect marketing strategies and 4) problems in plant management and production in as well as major fluctuations in market demand.

Although, the precast concrete construction for housing was not successful as expected, great efforts have been carried out to promote the industry in other civil engineering fields. To this end, the "Precast/prestressed Concrete Institute" (PCI) was established in the United States to enhance the development of precasting, in order to carry out the dissemination of up-to-date research developments, to prepare and distribute design manuals and guidelines among producers and professionals. In addition the institute promotes new methods and facilities for marketing, technology and production of precast concrete. The institute have a regular magazine through which new developments in the field are made known to the public.

Since the early 1960s the precast concrete has been used in the United States and some of the major projects can be mentioned here to show the degree of its utilization for civil engineering works.

2.2.7.1 The Boston College parking structure

The 989-car parking seven-storey building has 29,800m² of floor space. The cost of the structure was \$12 million US dollars out of which the precast contract amounted to \$4.3 million US dollars. The predominantly precast concrete parking structure shown in figure 2.1 is composed of 960 variety of architectural and structural precast/prestressed concrete components. It provides an aesthetic and functional link between the colleges lower and middle campuses. The objectives of project were to optimize the number of parking places and to facilitate smooth traffic flow while providing the college with an economical and aesthetically pleasing structure.

Precast concrete was an ideal solution for the structure because it had to be built within a tight budget and on a fast track schedule. Since completion, the parking structure has received high praise from the college and design community. It was selected as the recipient of the "Best Parking Structure" award in the 1995 PCI Design Awards Program.

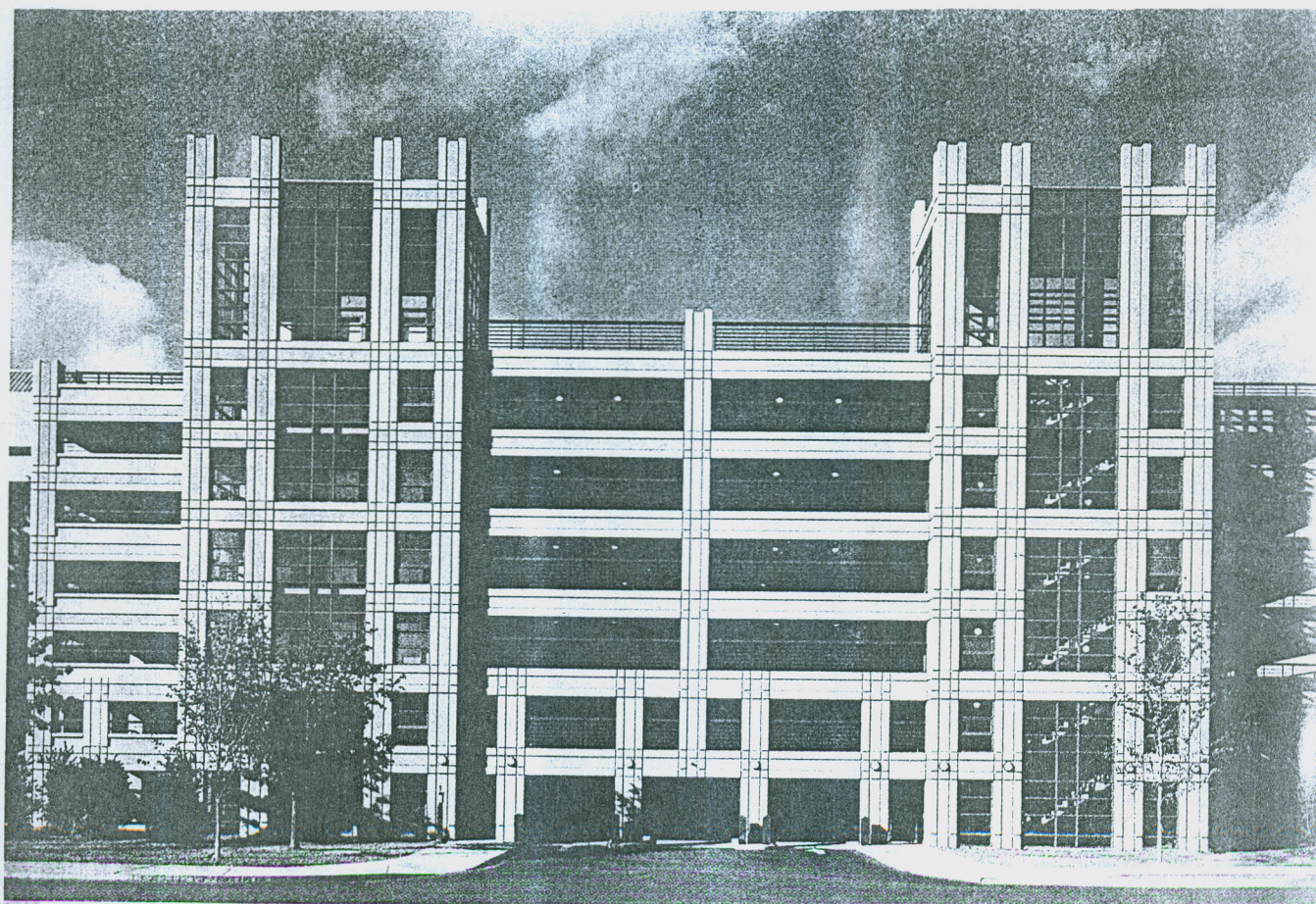


Fig 2.1 Front view of parking structure shows distinctive pattern of architectural precast columns and spandrels.

2.2.7.2 The Chesapeake & Delaware Canal Bridge This award winning \$18 million US dollars project is 1417m long. The structure constitutes the first major all-precast/prestressed concrete segmental cable-stayed bridge built in the northeast United States (see figure 2.2). The structure is part of the 76 kilometers Delaware Route 1 (SR1), the largest highway project with a total estimated construction cost of \$750 million US dollars. The major feature of the design is the use of precast delta frames, trapezoidal box girder segments, box pier segments and piles. All precast components were barged 290km to the bridge site.

The key purpose of the project was crossing the Chesapeake & Delaware canal, a major shipping channel and to address the design challenges. As a result precast/prestressed concrete segmental bridge was selected. The main span was 229m on the cable-stayed portion. The four primary precast concrete components used comprises of 972 piles, 463 Box pier segments, 984 trapezoidal box girder and 72 delta frames.

The advantages gained in the use of precast concrete for this bridge can be summarized as follows.

- Precast concrete shapes saved \$6.2 million US dollars of the total project cost.
- The use of precast concrete elements proved to be efficient and cost effective.
- Construction proceeded routinely and on schedule without undue difficulties.
- Erection of the precast elements was carried out from above using crawler cranes unimpeding the marine traffic below the bridge.

The canal bridge construction showed the efficient and economic use of precast concrete. The bridge project reflects the recent development of precast concrete and it has won the PCI Harry H. Edwards Industry Advancement Award for the year 1995.

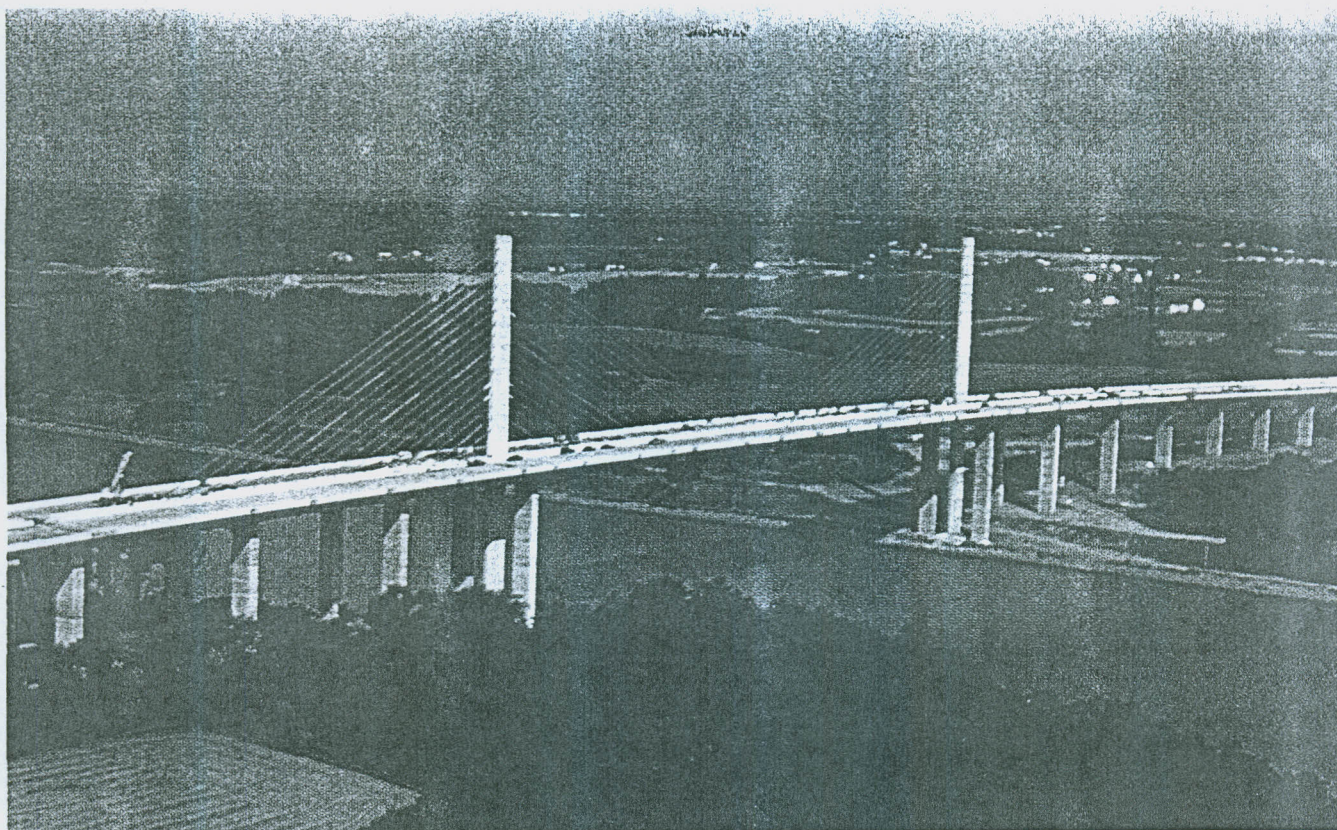


Fig. 2.2 Panoramic view of the nearly complete C&D Canal Bridge.

2.2.7.3 Hudson River Pier Project Precast concrete piers installed in the Hudson River off New York city will serve the dual purpose of protecting the Holland tunnel from errant shipping and providing access to a ventilation shaft tower for the tunnel 275m offshore. Precast concrete allowed work to proceed in the near-zero temperature of the frigid Hudson River and also allowed a high degree of quality control.

The precast concrete components used include 34 deck units, 36 pile caps with a cost of \$1.7 million US dollars for fabrication. Although sub-freezing temperatures delayed the casting of the joints between the precast elements, the project still was completed two months ahead of the completion deadline.

2.2.7.4 Lincoln Heights Water Tanks The project consisted of the construction of two water tanks with a capacity of 10 million gallons (37.9 million liters) each using precast/prestressed concrete in Spokane, Washington. The tanks were designed to replace a two-basin 5-acre open-type reservoir. A major feature of the structures is the combination of a single pie-shaped tees for the roof and single tees with exposed aggregate flanges for the circumferential wall.

Among the various studied alternatives, the precast water tank option proved to be the optional choice for the project. The new water tank combines strength, beauty, and economics providing drinking water storage at a very reasonable cost. The bid amount of the project was \$4.8 million US dollars out of which \$2.6 million US dollars was for precast concrete.

This award-winning project was designed and built within budget, on schedule and without an interruption of the water supply to the people. Substantial cost savings and enhanced appearance were achieved by partially burying the new tanks as shown in figure 2.3.

In general the engineering works with precast concrete that are carried out in the United States are so many. Some of these structures have won the PCI Design Awards.

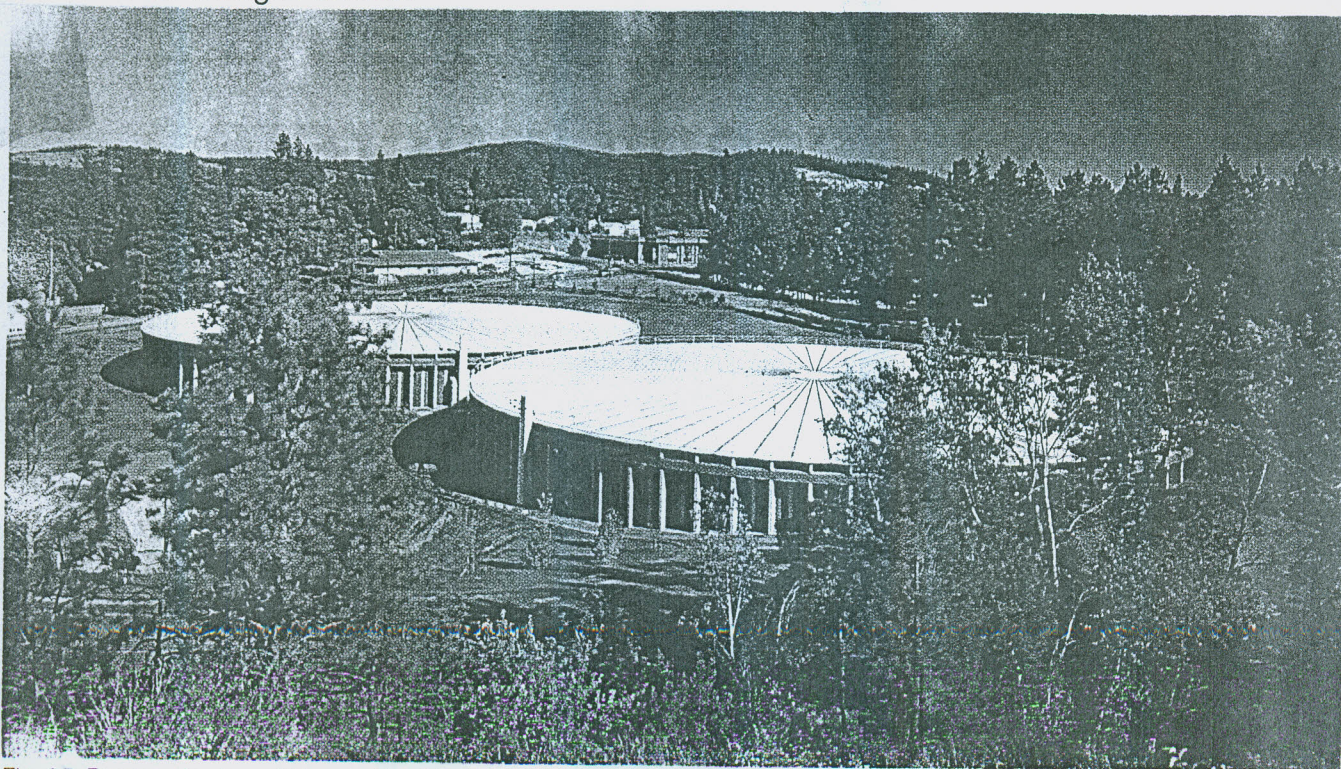


Fig. 2.3 Panoramic view of Lincoln Heights water tanks surrounded by attractive landscaping.

2.2.8 Yugoslavian Experience

The problems of the construction industry in Yugoslavia was in difficult condition immediately after the end of the World War II. The reasons for the construction industry's crisis lie both in the general crisis the country was undergoing and in the builder's' inadequate organization which consequently did not allow the proper application of knowledge and modern technology. So, the solution was based on the builders' greater independence and thereby their greater responsibility for their own fate and the tasks that society has entrusted to them. (Prof. Branko Zezelj 1987)

The demand for building of housing units efficiently and inexpensively pointed out to look for a precast technology application which is classified as industrialized building system. The new building technology of precast concrete, the IMS system, was meant to fulfill all requirements adequately i.e. structural safety, the fast rate of building and rational use of building materials and labor. Over the forty years of its application this building technology has proven its flexibility and adaptability to newly arisen situations and demands. Because of the stated characteristics, the IMS building technology has found its application in other countries as well, which were on very different levels of development which proved its compatibility to local conditions.

The IMS is based on modern building materials, technology and it employs materials and labors in the most efficient way compared to any other building technology. It is formed from precast concrete elements to be assembled afterwards in structures of different spans and different uses. The assembly of the elements is achieved through their prestressing by steel cables or ropes, in a way to form the monolithic entity.

Yugoslavia has started rapid post war expansion of housing development, the building of new house states and expansion of urban areas. To this end the introduction of the IMS prefabricated technology has played an important role. The first IMS buildings were erected in 1957 and by 1982 some 60,000 housing units and many schools, health institutions, office buildings, hotels had been erected (Milos, 1982).

Citing only some of the most note worthy buildings and housing estates erected by the IMS system, one can show the success of the system over the past years (see figure 2.4 and figure 2.5). A large number of residential buildings of this system has certainly been erected in Belgrade. Between 1963 and 1980, Napred of Belgrade built about 6000 apartments and in 1978 a work on 3600 apartments was commenced. Using IMS technology one contractor, Neimar, alone has built some 15000 apartments, several office blocks, schools a departments store and a hotel in Novisad.

Several contracting firms have been using the IMS technology. Two of them, the Technograd of Tuzla, has built 2500 apartments in new Alipasino Polje housing state in Sarajevo, and the contracting firm Kozara, has built about 7000 apartments in Banja Luka and its environs in the period from 1962 to 1982. These buildings have brought the IMS system valuable credentials since they withstood, with negligible damage or only slight damage to the secondary elements, the catastrophic earthquakes which hit the region in 1969 and 1981. (Milos 1982).

The IMS system has also gained recognition out side of Yugoslavia. It has been widely accepted in Cuba. It is applied in Hungary, Egypt, Angola, China, Tbilisi in Russia, Austria, Italy and of course Ethiopia.



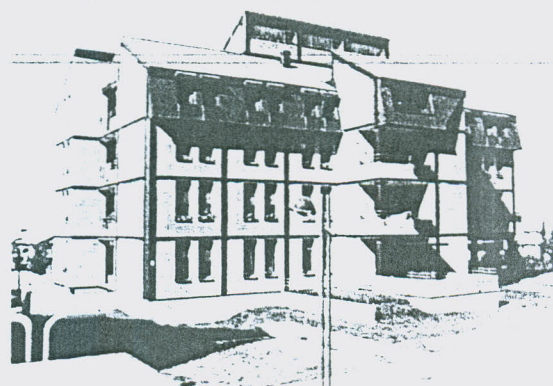
Hiseta housing estate in Banja Luka (1980)



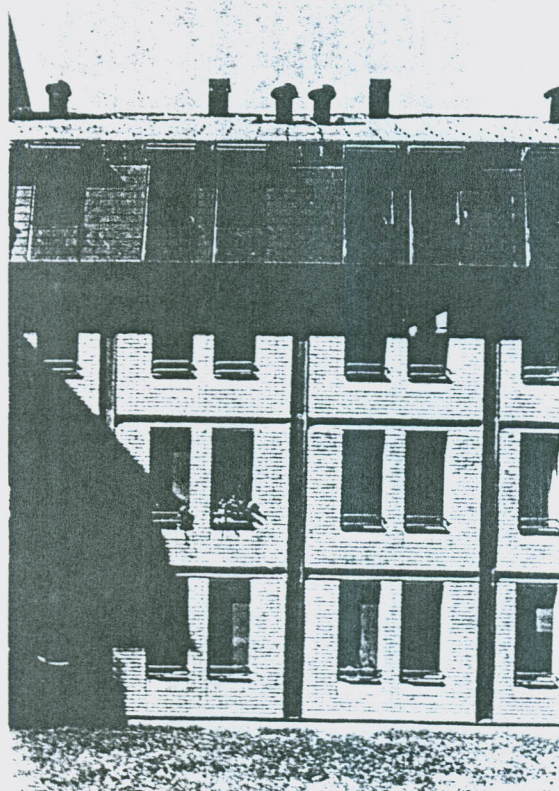
Hiseta housing estate in Banja Luka (1980)



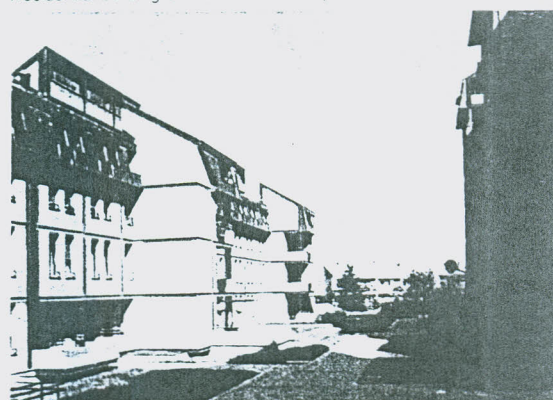
Galenika housing estate in Zemun (Belgrade) (1977)



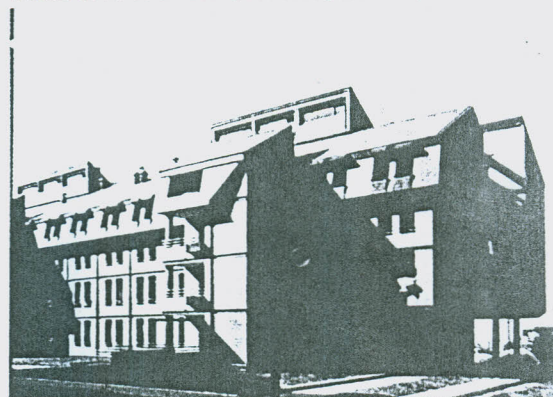
Residential building on the Cerak estate (1981)



Facade in the Cerak housing estate (1981)

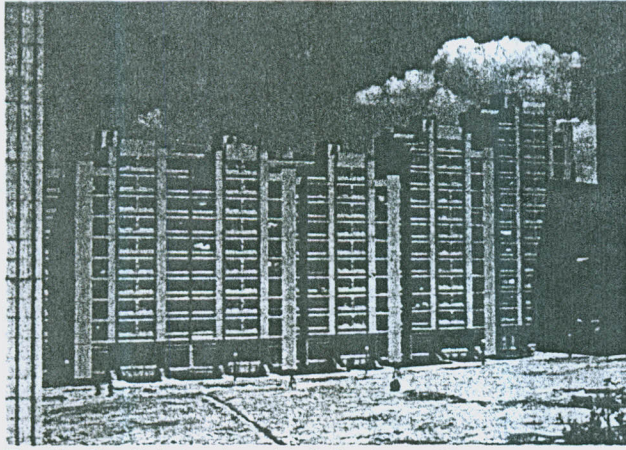


A street on the Cerak housing estate, Belgrade (1981)

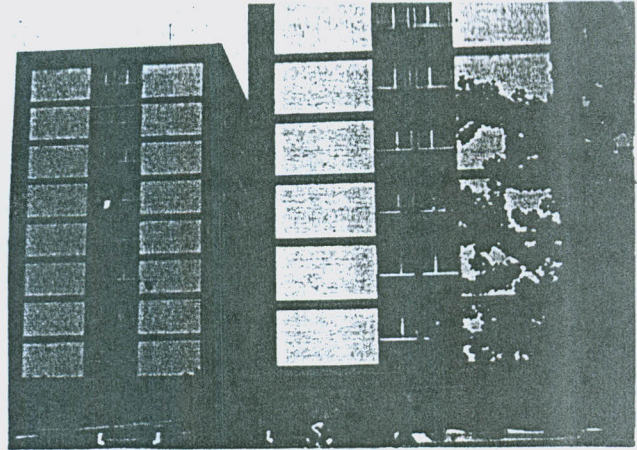


Residential building on the Cerak estate (1981)

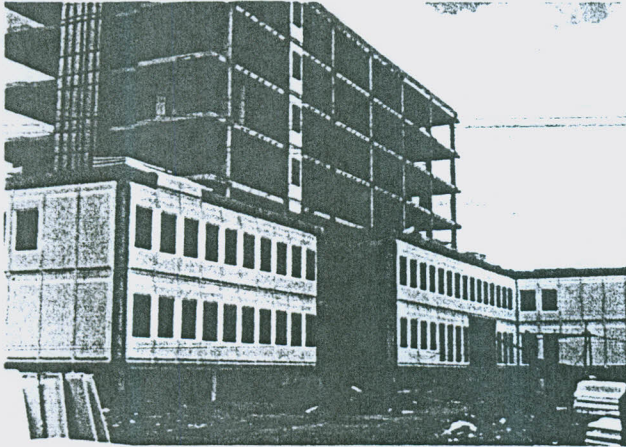
Fig. 2.4 Some of the buildings constructed by the IMS system in Yugoslavia



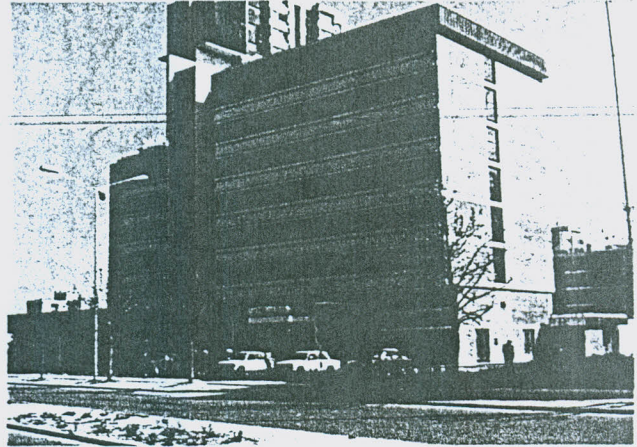
The Alipašino Polje housing estate in Sarajevo (1978)



The Liman housing estate in Novi Sad (1969)



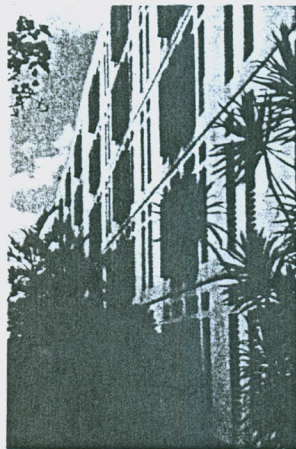
Medical Centre in Niš (1982)



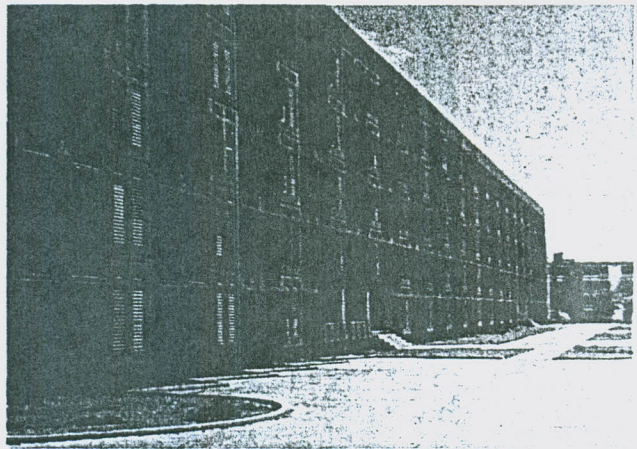
Hotel in Novi Sad (1980)



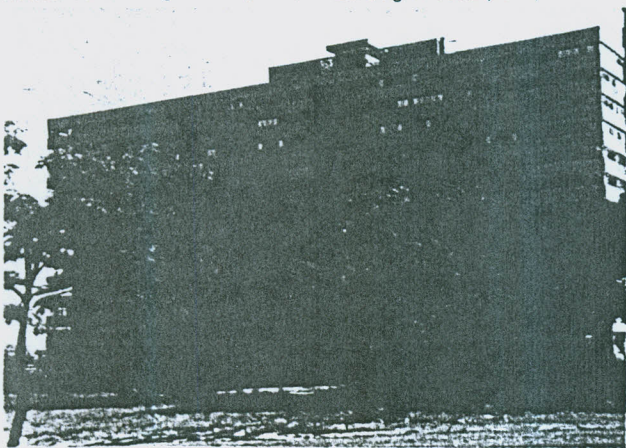
Residential buildings in Niš (1977)



Building in Cuba (1970)



Building in Cuba (1970)



Alamar housing estate in Havana



Alamar housing estate in Havana (1976)

3.0 Ethiopian Experience in Precasting

3.1 Historical background

The utilization of concrete as a building material was not that much wide spread before the Italian invasion. During the Italian occupation a wide range of plain and reinforced concrete arch bridge structures were built all over the main highways. Stone was used for the construction of buildings which stand to the present day in the military garrisons of that time and these eventually grew to urban centers. Even after the independence, the utilization of concrete as a building material was mostly limited to the capital city, Addis Ababa. As shown in Table 3.1 about 73.3% of the housing units of the country is made up of the traditional construction materials, wood and mud, which on the other hand shows that the degree of cement consumption is low. Moreover, the majority of the existing housing units in Addis Ababa, about 81.8%, are built using wood and mud. (CSA, 1984)

Generally, the major construction materials for walling of the housing units in urban areas were wood and mud (72.4%), while the roofing was of corrugated iron sheets (estimated 81.4%) supported by wooden trusses or rafters. On the other hand, little use of concrete was made as a building material in major urban areas with a less effort in other localities. The reason for the slow development of concrete construction may be the low economic development of the society, limited technical knowledge of concrete construction and the tendency of the people to have the traditional building as they were and these have restricted the emergence of new local construction companies within the existing foreign construction firms.

country. The unit has constructed various elementary schools preparing on-site facilities to produce precast concrete elements. The main elements produced were somewhat I-shaped columns and small wall elements. The ESBU model elementary schools can be seen in various parts of the country. Locally available materials were mostly used in the construction except for cement, steel and roofing. The production of the elements were carried out on the site and the time required for erection was minimum. The columns were light in weight that the requirements of crane was out of question. Ultimately, the unit emerged as a big construction entity, the former Ethiopian Building Construction Authority, in charge of conventional construction works abandoning the precast concrete works.

Precast concrete fence poles with an effect of minor structural use are mostly used for the fences of big projects. In general, the use of these poles is limited to the localities where other construction materials are scarce. The quality of such precast concrete poles usually depends on the quality control, the skill of workers as well as the conditions of the production site. Usually, as little attention is given to the quality control, one can observe inferior quality products in different places.

3.1.2 Project oriented precasting - Special housing project

The Special Housing Project in Addis Ababa came into vision in order to accommodate the needs of the large diplomatic community and many expatriates working in international organizations. The project was intended to use a large area for the development of a housing and commercial complex. In the first phase of the program, it was envisaged to construct 2,500 apartments including commercial services, sports and health facilities, and embassy residences. The Ministry of Urban Development and Housing being a client has assigned the construction of the first 500 apartments to Cooperativa

Muratori e Cementisti (C.M.C) of Ravenna Italy. The foreign currency component of the contracts has been funded by a pool of Italian Banks with special facilities granted by the Italian Government.

The C.M.C has built a precast concrete factory for the Special Housing Project on an area of 124,000 square meters to produce precast concrete components used in the construction. All the systems and equipment needed for the production of precast elements were installed in the factory. The production of slabs was with a potential daily output of 300m² of slab. The precast elements produced at the site include cladding panels finished in smooth marble chipping with decorations, partition walls, stairs and landings, balcony parapets, and cornices. As many as 40 elements, amounting to 400 square meters, could be produced in the central section of factory out of which 10,000 elements were used for Special Housing Project. Chemical additives and steam were used to speed up the concrete curing process (Foster, 1987).

The investment made including all the machinery used for the Special Housing Project and the various workshop for precasting, amounts to approximately \$10 million US dollars.

The Special Housing Project constitutes to be the first project where precast concrete elements were used efficiently, specially by a foreign construction firm to introduce diverse designs in Ethiopia. The design calculation is based on Italian standards and has made use of automated process.

The precast concrete produced by the C.M.C. was later utilized for two projects, the UN Economic Commission for Africa head office complex in 1994 and the Patriarch Palace Building project in 1996 both in Addis Ababa. The decorated wall panels used for the construction of these buildings are architecturally attractive and the Palace building has some carved features of ancient Ethiopian building styles of Lalibela and Axum.

3.2 Precast concrete construction

3.2.1 The Prefabricated Building Parts Production Enterprise (PBPPE)

Due to its highest technical effect, modern methods of construction - prefab against traditional construction- has been considered as a leap to transform society to the future through industrialization. Among the steps taken in this direction, the establishment of the IMS system, the Prefab Housing Factory, in Addis Ababa constitutes the corner stone in the evolution of the building industry.

In the late 1970's and 1980's, the demand for housing was immense that the government being the only facilitator for shelter could not meet the ever rising demand. As a result it was decided to introduce a new building technology, the prefabrication of concrete structural elements. The technical assistance was obtained from the former Yugoslavia and the IMS system, of a Yugoslavian firm with more than 30 years of experience in the field was selected. The IMS system was a patent of the Institute for Testing Materials for prestressed concrete, and its acceptance led to the establishment of the former Prefab Housing Factory for prefabrication in 1984. The Factory was organized administratively under the former Ethiopian Building Construction Authority. The initial total cost of the factory was estimated to be Birr 13 million which later on raised to Birr 17 million due to the delays in the implementation. The prefabrication factory started the production of structural elements in 1986.

The main objectives of the factory were:

- To alleviate the shortage of housing in Addis Ababa and the surrounding area,
- To promote the building industry by raising the capacity for mass production of structural elements,
- To produce building parts and execute the erection of such parts at building sites,
- To reduce the construction cost required per built up floor area,
- To minimize the use of formwork and by so doing conserve the natural forest,
- To produce quality and standardized structural elements as per the need of potential house builders of the inhabitants of Addis Ababa,
- To expand concrete production technology through prefabrication of large wall panels, doors and window.

The design and erection of the first Ethiopian prefabricated residential building constructed on the Bole road which consisted 150 flats, has opened new opportunity to implement various technical and architectural possibilities in the IMS system. The construction of the building commenced in April 1985. There after similar design and construction solutions have been used on several construction works where the IMS system was deemed suitable.

To familiarize the technology, the products of the factory were assumed to be taken by the then Ministry of Construction for the mass production of residential buildings under the existing housing policy guidelines. However, as a result of the frequent changes in the policy, the presumed coordination was not materialized as was expected.

3.2.2 Organization of the Enterprise

The Prefabricated Building Parts Production Enterprise (PBPPE), previously known as Prefab Housing Factory (PHF) at a department level under the former Ethiopian Building Construction Authority (EBCA) was reestablished as an autonomous business entity in accordance with the new economic policy in 1993. It was generally in charge of the three phases of prefabrication process, the production, transportation and assembly (erection). The production of the structural components take place in the factory about 10 kms from Addis Ababa at Kaliti. Transportation of the produced components to the construction site is carried out by heavy vehicles of the establishment and consequently the erection has been performed by the technical staff assigned for the work. Initially, in order to make prefab viable, the distance to the construction site, the weight of the components as well as its easiness for transportation were taken into consideration in the design of the precast elements.

After the re-establishment of the factory, in order to make the enterprise profitable, it was decided to extend its functions with additional tasks parallel to the production and erection of precast concrete. Consequently, the following were included in the work schedule of the enterprise.

- Provides ready made concrete mix using truck mixer wherever needed all around Addis Ababa,
- Based on work orders, produces concrete products such as fence poles, stairs, manhole and covers, curbs etc.,
- Hire or lease out the services of construction equipment such as truck cranes (kato cranes), tower cranes, loaders, excavators and rollers,
- Produces metal doors, windows, water tanks and gates receiving work orders,
- Take office/residential building contracts engaging in conventional construction works using precast as well as cast-in-situ concrete methods and finishing works.

The organization of the newly emerging enterprise was made in such a way that it facilitates the overall activities of the enterprise. Accordingly, the main parts of the organizational structure is as shown in figure 3.1. The major departments of the enterprise are under the direct direction of the General Manager. The parallel relationships between the production and construction departments which sometimes leads to arguments is facilitated by the Manager. If the production and construction departments are organized under one strong department the work relation may be improved since the design solutions, production requirements, the erection and the coordination of construction projects can be smooth and efficient. An improvement in management skills and in coordination can help to gain better performance. The quality control section performs its tasks independently. The adoption of strict quality control mechanisms constitutes a paramount task to achieve quality concrete.

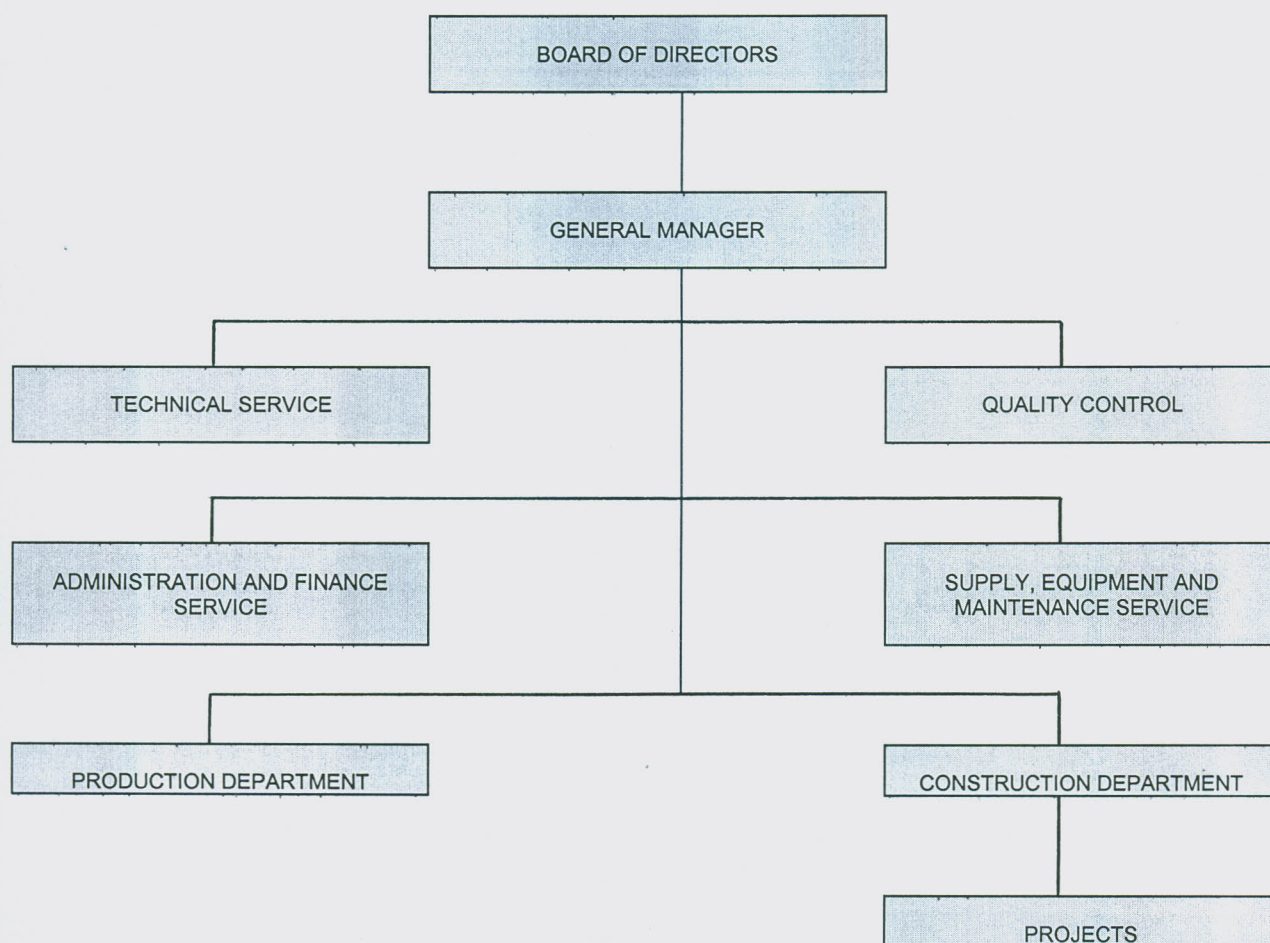


FIGURE 3.1 ORGANIZATIONAL STRUCTURE OF PBPPE

3.2.3 Resource of the Enterprise

Following the re-establishment of the enterprise, the government has authorized Birr 11.0 million initial capital contribution to the enterprise. The fixed assets of the enterprise constitute the main capital contribution.

**Table 3.2 Prefabricated Building Parts Production Enterprise
Fixed Assets Revaluation Summary
As of July 7, 1993.**

Item Group	Fixed Assets	Revalued amount (Birr)	Share %
I	Office furniture and equipment	131,189.88	0.6
II	Factory assembled machinery & equipment	5,177,504.29	25.2
III	Transport heavy trucks and light vehicles.	1,868,720.83	9.1
IV	Construction equipment (cranes, loaders, excavators, mixers, etc.)	1,387,948.59	6.7
V	Buildings (Office, factory, stores, etc.)	12,013,745.20	58.4
	TOTAL	20,579,108.79	100

Source:- PBPPE fixed assets estimation, May 1993.

According to the results of revaluation, Table 3.2, in 1993 the total fixed asset of the enterprise amounts to over Birr 20.6 million, taking into account the inflation as well as the depreciation. The Factory building, office and stores constitutes the major share of the asset with 58.4% followed by factory assembled machinery and equipment with 25.2% share of the asset. The factory assembled machinery and equipment include the essential equipment for production such as a batching plant, different metal molds, tower and bridges cranes, stationary vibrators, steam curing facilities, steel cutting and grinding machines. In addition the enterprise owns heavy transport vehicles and construction equipment for erection of precast elements.

3.2.4 Manpower of the Enterprise

The manpower of the enterprise engaged in the production process as well as erection has been over 440 over the last 10 years. The majority of the workforce in the past were employed either on contract or casual basis. However, since 1994, the new organizational structure has permitted the status of 255 workers to be on permanent basis. This changed the trend in the previous years with respect to employment, and as a result the number of contract/casual workers has reduced. In line with the involvement of the enterprise in finishing works, the number of the workers has increased bringing the total number of the workers to 638 in 1997.

Table 3.3 Man power of the Enterprise

Employment Type	1993/94	1994/95	1995/96	1996/97
Permanent	52	255	258	244
Contract	46	2	10	26
Casual	315	198	180	368
Total	413	455	448	638

Source:- PBPPE , annual plan and performance reports

The number of permanent employee was relatively low compared to the total employee. Taking the 1994/95 data, one can observe that, the composition of the workers shows low ratio of professional staff. Technically capable professionals are three civil engineers, three building engineers, one mechanical engineer and high school technicians engaged in the production as well as the erection process. With the existing few professionals of the enterprise, it was unlikely to change the current standardized elements produced and at the same time it was unusual to expect new design modules.

3.2.5 Operating income and expenses

The annual profit and loss statements of the enterprise show that the enterprise was profitable for the first four years under the former EBCA. After the restructuring, except for the year ending July 7, 1995, one can see from Table 3.4, that the enterprise was without a loss. In 1994 and 1996/97 it did have a good performance with a profit margin of more than 1 million Birr.

**Table 3.4 Profit and loss statement of the enterprise
(As of July 7 of the respective years)**

In '000 Birr								
Year	1985	1986	1987	1988	1993/94	1994/95	1995/96	1996/97
Total income	862.9	3,871.3	3,632.4	3,340.7	3,462.6	3,023.9	6,469.8	11,517.2
Total expenses	862.9	3,089.8	3,023.9	2,988.8	3,434.4	2,020.9	6,710.2	9,729.4
Net operating income	-	781.5	608.5	352.9	28.2	1,003.0	(-240.4)	1,787.8

Comparing the profit obtained in the past, the trend was in a decreasing order except for the years 1994/95 and 1996/97, the years of good performance of the enterprise with a profit margin of more than Birr 1 million. The operating efficiency of the enterprise measured by the ratio of gross profit to net sales shows variations over the last 14 years being inconsistent from one period to the other. The ratio of the net income to net sales which constitutes an important measure of success achieved in marketing also indicates unfavorable conditions. Furthermore, taking total assets of 1993, the ratio of the net sales to total assets shows how effectively the firm has utilized its assets in marketing which is low except for the years 1995/96 and 1996/97. In the same way, the ratio of net income to total assets which shows an overall rate of return on the total assets of the business is well below the prevailing interest rate except for the year 1996/97. This confirms the previous conclusion that the financial status of the enterprise can not be considered favorable.

3.2.6 Construction of precast concrete buildings

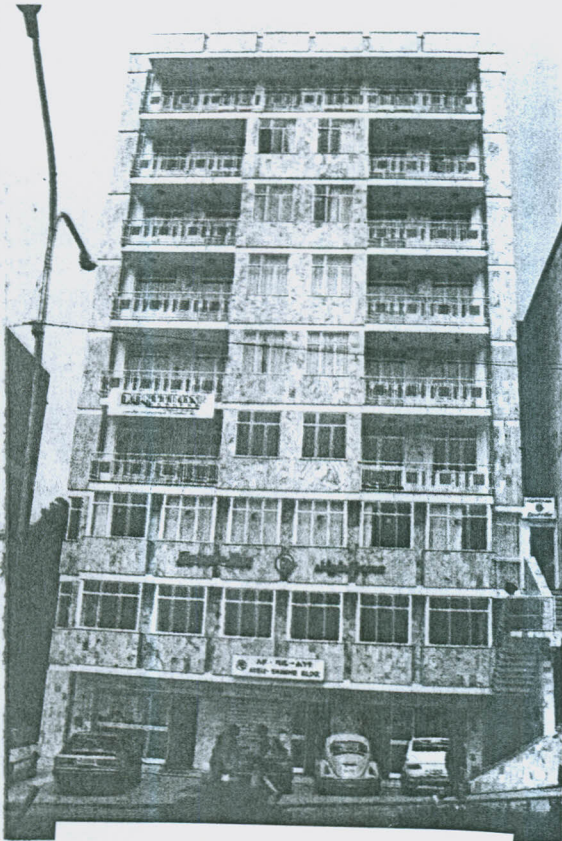
Immediately after its foundation, the Prefab Housing Factory started the production of structural building parts. At the time the Ministry of Construction was supposed to take all the products for mass housing construction works. Due to lack of proper planning and coordination, the building units produced during those time were not consumed and many of the previous products remain in the factory premises upto the present day.

As a result of low development of the construction industry in Ethiopia, the only establishment to perform the erection of prefab elements was the Prefabricated Building Parts Production Enterprise. So the factory has been engaged in the production, transportation as well as the erection of the prefabricated structural elements since its foundation. The involvement of other contractors was limited to finishing works. of the assembled building.

The PBPPE has carried out the production of various building parts and their consequent erection at the building sites. It has assembled various residential, office and shopping buildings as shown in figure 3.2 and 3.3 and as listed in Table 3.5. So far, the enterprise has carried out the construction and finishing works of over 17 projects with a total cost estimate of over 30 million Birr.

Table 3.5 Construction works executed by the PBPPE

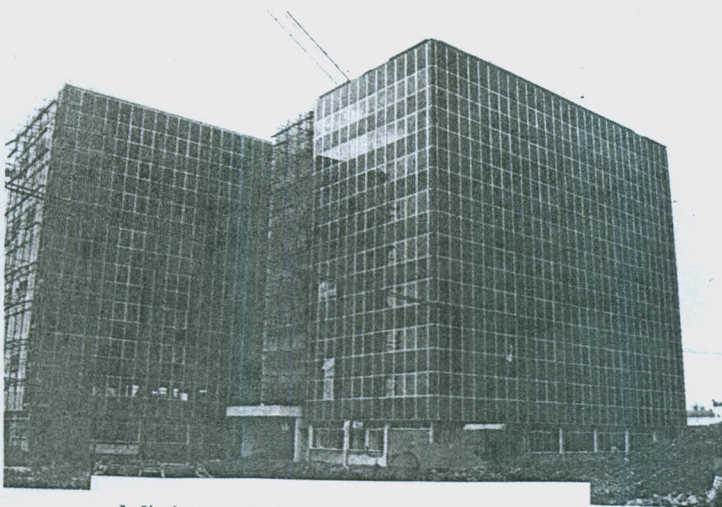
lt. no.	Project	Contract amount ('000 Birr)	Type of building	Type of work	Status
1	Ministry of Finance	3,478.4	Office	Erection	Completed
2	Meskel flower	3,455.9	Hostel	Erection/finishing	Underway
3	Beklobet building	3,869.1	Office	Erection/finishing	Completed
4	T. Berta	443.3	Office/shopping		
5	Rental Houses A.		Office	Erection	Completed
6	Rental Houses A.		Hostel	Erection	Completed
7	Ayu & family	1,492.8	Office/Shopping	Erection	Completed
8	Rift Valley	1,290.8	Hotel	Erection	Completed
9	Ledeta building	2,020.9	Office/Shopping	Erection	Completed
10	Barek Agency	1,079.3		Erection	Completed
11	D/Zeit Road	5,056.8	Office	Erection/finishing	Underway
12	Civil Aviation	3,434.7	Garage/Store	Conventional	Underway
13	Nyala Insurance	31.8	Office	Maintenance	Completed
14	Mina Trading P/C	3,408.6	Office/Shopping	Erection	Underway
15	Lemiwodish Building		Office	Erection	Completed
16	Arega (Almesh Building)		Office	Erection	Completed
17	Telecommunication (R.P.C)	300	Manholes	Production	Underway
18	Ras Amba		Hotel	Erection	Completed
19	Council of Ministers		office	Erection	Completed



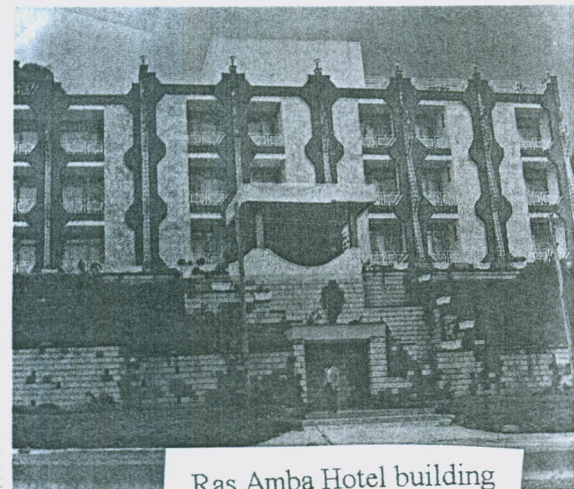
Almesh Office/shopping building



Office and shopping centre



Ministry of Finance Office building



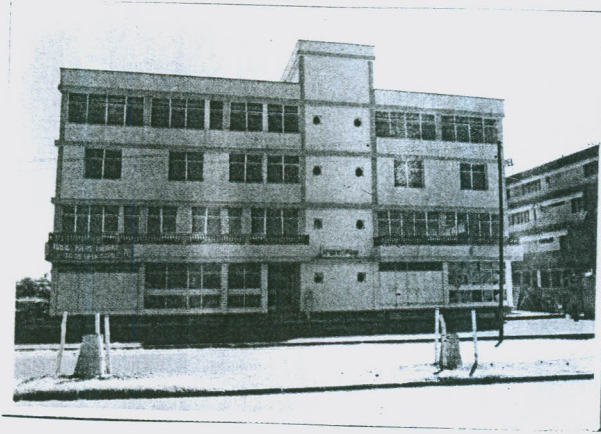
Ras Amba Hotel building



Rental Houses Administration, modern apartments



Residential apartments



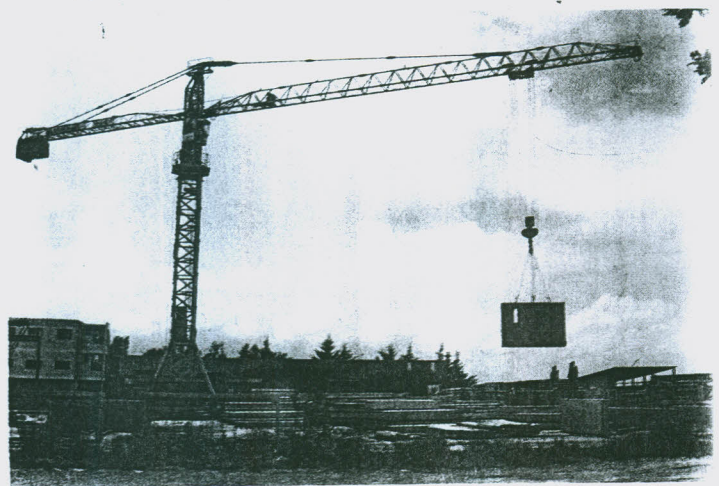
Lemiwedish office and shopping building



PBPPE Head office model building

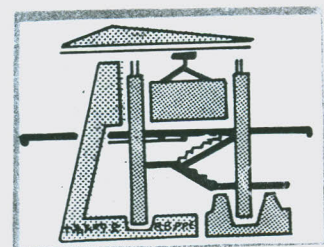
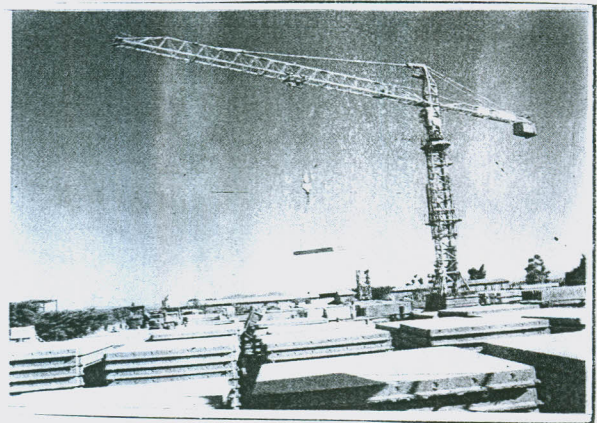
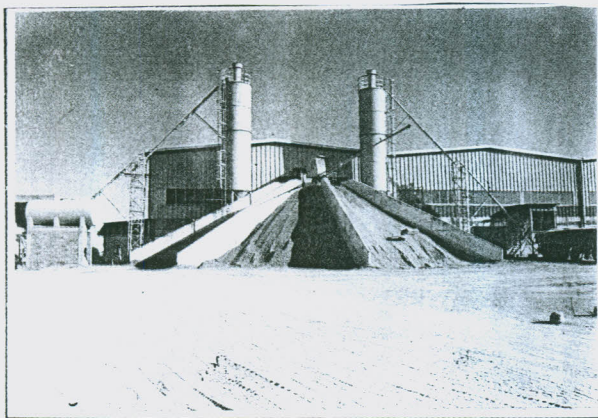


Office building



IMS produced elements at the factory premises

IMS factory in Addis Ababa



3.2.7 Design Capacity of the Factory

The production of members is organized in a factory with the design capacity to produce structural elements for the construction of 50,000 m² built up gross surface area. The initial capacity was estimated based on the following assumptions.

- member production for residential buildings with up to 5 floors (45%)
- member production for residential buildings with upto 10 floors (45%.)
- production of members for public buildings (10%)
- annual working days of 250 and 44 hours per week with one working shift
- capacity of finished members storage on the factory grounds 30- 60 days

The additional conditions required for the production include the following.

- steam curing chambers are to be used to accelerate concrete hardening for floor slabs and all soffits,
- conveyance of fresh concrete from concrete plant to the work station is carried out by crane scoop,
- vibrating tables, immersed vibrators and hand tools are to be used,
- traveling cranes are to be used to provide in door conveyance of members and tower crane for depositing of the products at the storage site and for their consequent loading on transport vehicles.

The production of members for residential and public buildings stipulate that the residential buildings constitutes a gross surface area of 45,000m² , 50% of which is for buildings with upto 5 floors and 50% for buildings with up to 10 floors. The production of members for the construction of public buildings of gross surface area of 5000 m² is also taken as the annual capacity of the factory.

Accordingly, it was estimated that the average participation of individual prefabricated members per square meters of gross accommodation area, to the IMS norms, is provided in Table 3.6.

**Table 3.6 Average participation of each member
(Residential building)**

Ord. NO.	Members	pcs/m ²	for 45,000m ² /pcs	Daily production pcs
1	3 - floor column 30/30 and 34/34	0.0262	1182	5.15
2	floor slabs	0.0444	1998	8.72
3	Lift and stair floor slabs	0.0051	230	1.00
4	Cantilever floor slabs	0.0196	882	3.85
5	Floor-slab soffits	0.0178	880	3.49
6	Soffit on lift & stair floor slabs	0.0020	92	0.40
7	Soffit on cantilever floor slab	0.0098	441	1.93
8	Peripheral girders	0.0305	1380	6.00
9	Stair flights	0.0099	444	1.94
10	shear walls	0.0197	888	3.88
11	Stair landings	0.0050	225	0.97
12	Foundations	0.0066	298	1.30

* Calculated on the basis of 229 working days

Source:- IMS Housing Factory, Technical design Book 1.1 Belgrade 1984.

Similarly the participation of prefabricated members per m² of gross surface area of public buildings and number of planned annual assignment is as given in Table 3.7

**Table 3.7 Average participation of each member
(Public building)**

Ord. NO.	Members	pcs/m ²	for 5,000 m ² /pcs	Daily pcs
1	Columns, two floor 50/50cm	0.0158	79	0.35
2	Floor slabs 6.0/7.20m	0.224	112	0.49
3	Cantilever floor slabs 7.20/2.00m	0.0030	15	0.07
4	Cantilever floor slabs 6.00/2.00m	0.0012	6	0.03
5	Peripheral girders 6.0m	0.0056	28	0.12
6	Peripheral girders 7.20m	0.0112	56	0.24

* Calculated on the basis of 229 working days

Source:- IMS Housing Factory, Technical design Book 1.1 Belgrade 1984.

The structure of the IMS system adopted in Ethiopia is a prefabricated square cells, in standard sizes of 4.20x4.20m and 6.0x7.20m. The cell is formed by four columns and a coffer floor slab standing between them, and at the same time accepting the vertical loading. The connecting up of the columns and the ceiling slab into a monolithic entity is effected with the means of prestressing cables which are pulled through openings in the columns on the ceiling-slab level, and through the empty space between the adjoining ceiling slabs. Prestressed girders of the skeleton system are subsequently formed from peripheral webs of the floor slab by filling up the empty space with concrete, which at the same time also acts as cover to the cables. The cables are mostly set and tensioned rectilinearly, while in the case of greater spans or loads, the necessary eccentricity and deviation of the cables can be effected subsequently by lowering the cables. The cables are set in two orthogonal directions, and their tensioning can be carried out before concreting the contact points between floor slab and columns.

The reception of inferences arising from horizontal forces of wind and earthquake is assigned partly to the skeleton and mostly to the concrete stiffening shear walls. The shear walls are concrete panels fitted between two columns in the same axis, so that connected with columns by the prestressing force on the ceiling slab level, where they form stiffening walls. In principle they are prefabricated members, the number of which is to be worked out, so that they can act as horizontal force bearing members without additional connections. The shear walls can be cast-in-situ if it is desired for high earthquake resistance and alike.

3.3 Survey on the use of Precast Concrete

3.3.1 Objectives of the Survey

A sample survey was conducted in August 1997 in order to collect professional opinion on the production, use and development of precast concrete in Ethiopia. The survey was a sample survey that a simple questionnaire was prepared and distributed among professionals working in construction and related activities. The selected groups have direct relationship to the building industry. The group comprises of the following.

- Academicians :- Who are in charge of research and teaching activities in higher institutions,
- Producers :- the professionals and technicians who take part in the production and erection of precast concrete elements at PBPPE,
- Consultants:- Designers, (architects and Engineers) whose major task is the design of various projects both at the government and private consulting offices,

- Contractors:- This group composes of building contractors and professionals in charge of construction works, the erection of reinforced concrete buildings and other civil engineering works,
- Users:- In this category, the professional staffs representing the clients/investors both from private and government institutions are included.

The objectives of the survey can be summarized as follows:

- To know the degree of precast concrete utilization in Ethiopia,
- To assess the preferences in the choice of construction materials,
- To know the type of construction materials preferred traditionally by professionals involved in the building industry,
- To investigate whether the designers are aware of the existence of precast concrete elements production in Ethiopia and their attitudes towards its use,
- To evaluate the performance of precast concrete buildings so far built in Ethiopia for any structural failure if any,
- To assess the inconveniences in the use of precast concrete elements during production, execution and finishing works,
- To investigate the reasons behind the slow development of precasting in Ethiopia, and,
- To collect professional opinions and useful suggestions for future development in the field.

3.3.2 Sample distribution

To conduct the survey, a questionnaire was prepared and distributed with questions and suggested possible answers related to the use of concrete as a building material in general and the precast in particular. 50 questionnaires were distributed to professionals working in Addis Ababa University, Prefabricated Building Parts Production Enterprise, Building Design Enterprise, Transport Construction Design Enterprise, Ethiopian Roads Authority, Agency for the Administration of Rental Houses, SB Consultant, Ministry of Works and Urban Development, Elmi Olindo contractor, Addis Ababa Education Bureau, Addis Ababa Administration, two private contractors, Ayu Shashe PLC. and Helen Building PLC. owners, and the Institute of Agricultural Research. In spite of the reluctance to answer such questionnaires, 40 of the distributed questionnaires were collected for further analysis. The respondents were architects, technicians and engineers working with different positions at the mentioned institutions. So, it was decided to take equal markings giving equal weight to their responses. The composition of the respondents is as shown in Table 3.8.

Table 3.8 Composition of the respondents

S.No.	Relation to the building industry (duties)	Respondents	%
1	Academic or research Institution	4	10.0
2	Designers, consultants offices	11	27.5
3	Construction supervision	6	15.0
4	Contractors	4	10.0
5	Users /investor/ owners	6	15.0
6	Precast concrete producers	9	22.5
Total		40	100

3.3.3 Analysis of the existing Situation

The analysis of the responses focused broadly on the choice of construction materials used in the industry, the use of precast concrete and the factors that contributed to its slow development, its utilization for other civil Engineering works, and the measures to be undertaken in order to promote its development in the future.

3.3.4 Construction materials preference.

Based on the survey results, the construction materials widely preferred in the building industry, was found to be cast-in-situ reinforced concrete especially in modern construction works. About 93% of the interviewed professionals confirmed that they use cast-in-situ reinforced concrete in most of the cases. This was followed by the use of precast concrete which constitutes 40% as shown in Table 3.9.

Table 3.9 Materials of preference in the building industry

Item	Construction material mostly used	Number of marking	%
1	Conventional mud & wood (ጥቃብ)	3	7.5
2	Reinforced concrete	37	92.5
3	Precast concrete	16	40.0
4	Stone masonry	3	7.5
5	Steel construction	5	12.5

The reasons behind “why reinforced concrete is preferred?” was also indicated by the respondents. It was preferred because of its simplicity in construction works and its availability. The reasons are summarized in Table 3.10.

Table 3.10 The reasons behind “the preference of materials”

Item	Reasons for the preference	Number of marking	%
1	Traditional use	4	10.0
2	Easy to use and the technology is simple	26	65.0
3	Cheaper than other construction materials	7	17.5
4	Easily available	16	40.0

After the existing preference was known, a general proposal or recommendation was forwarded by the respondents considering the level of development of Ethiopia. Accordingly, 72.5% and 62.5 % of the interviewed professionals have recommended the use of precast concrete integrated with cast in-situ and reinforced concrete alone respectively. This shows that the majority of the professionals are in favor of reinforced concrete as a building material be it precast or cast -in-situ. The recommendations are shown in Table 3.11. The reasons behind the recommendation are summarized in Table 3.12, where the simplicity in the technology and its appropriateness to developing country like Ethiopia was emphasized.

Table 3.11 Construction material recommendations

Item	Type of materials	Number of marking	%
1	Steel construction	3	7.5
2	Reinforced concrete	25	62.5
3	Precast concrete integrated with cast-in-situ concrete	29	72.5
4	mud & wood (እንጨትና ቱቃ)	4	10.0

Table 3.12 Reasons for the recommendations

Item	Reason for the recommendation	Number of marking	%
1	Cheap and available (affordable) by the majority of the community	9	22.5
2	Simple technology that one can use, less manpower and least qualification of labor	20	50.0
3	Most people prefer it	3	7.5
4	It is appropriate for developing country like Ethiopia	23	57.5

3.3.5 The Use of Precast Concrete

Having seen the opinions of the overall preference of construction materials in the building industry, the precast concrete was treated in detail. According to the survey results, the majority of the respondents about 95%, know that there exist a precast concrete production center in Ethiopia. Most of them about 40%, have known the existence and functions of the center for more than 10 years. Those who have known the enterprise for less than five years constitute only about 26%. From this, one can conclude that the existence of Prefabricated Building Parts Production Enterprise (PBPPE) is widely known among the professionals over the last ten years.

Precast concrete centers, other than the PBPPE is not known for 60% of the interviewed professionals. This indicates that the existence of precasting is by far out of vision. This assures the view of the respondents that the use of precast concrete is not wide spread in Ethiopia. Accordingly, about 68% of the respondents agree to this comment. Those who have certain relations to the precasting techniques, which constitutes about 55% of the respondents, roughly estimate that there are more than 20 buildings that have been built in

Ethiopia using the precast concrete technology. About 15% think that the number of precast buildings constructed in Ethiopia are less than 4.

Efforts were made through site visits and interview with resident engineers to know if there exists any failure or inconvenience of precast concrete in Ethiopia. The author could not find any structural failure except some inconveniences for electrical and sanitary installations which of course were due to negligence at the design and production phases. Poor workmanship during production have led to poor finishing quality of the products seen at some buildings. Adequate quality control could have avoided such inconveniences, which otherwise could not be considered as demerits of precasting. About 72% of the respondents to the questionnaire, confirmed that there are "noted inconveniences" of precast concrete in Ethiopia. The inconveniences of the precast concrete noted can be summarized as shown in Table 3.13.

Table 3.13 Inconveniences of Precast concrete

Item	Type of inconveniences	Number of marking	%
1	Structural failure	0	0
2	Not convenient to install electrical & sanitary fittings	13	72.0
3	Precast concrete faces are hard to plaster or decorate	8	44.0
4	It is not easily compatible with cast-in-situ concrete	5	28.0
5	Architecturally not flexible	3	17.0
6	Leakage in slabs at sanitary and electrical installations	1	5.0

According to the survey results, it is believed that the use of precast concrete is not wide spread and this reflects the existing reality. There are various factors that contributed to its slow development. Among the various

factors, it was believed by 63% of the respondents that "unawareness of public" constitutes the major drawback. But about 48% of the respondents said "it is due to the an availability of preferred precast sizes". The summary of the possible reasons behind the slow development of precasting is presented in Table 3.14.

Table 3.14 Possible factors that led to the slow development of precast concrete in Ethiopia

Item	Possible reasons	Number of marking	%
1	Unawareness of public	17	63.0
2	It is damn expensive	2	8.0
3	The technology is not so simple and flexible	8	30.0
4	Aesthetically not attractive	9	33.0
5	Preferred sizes are not available	13	48.0
6	Afraid of it. It may collapse	1	4.0
7	Designers are not well informed and are not inclined to use it	1	4.0

3.3.6 Importance and future prospects

The advantages of precast concrete as compared to other construction materials was felt by the majority of the respondents. The advantages were seen from different point of view. Some of the exclusive advantages as compared to cast-in-situ concrete are summarized in Table 3.15. The speed of construction followed by the quality of the products and the non requirement of formwork are considered as the main advantages of precast concrete with 92.5%, 60% and 60% of the respondents, respectively.

Table 3.15. Advantages of precast concrete over the cast-in-situ concrete

Item	Advantages	Number of marking	%
1	Its cost is cheap	10	25.0
2	No need of formwork	24	60.0
3	The quality of the product is superior	24	60.0
4	Architecturally attractive	5	12.5
5	The speed of construction is fast	37	92.5
6	Highly resistant to earthquake forces	2	6.0

In spite of the indicated advantages, 75% of the respondents think that the type of the existing structural elements produced in Ethiopia are not sufficient. Accordingly, they reiterate that the choice for design alternatives is limited. At the same time if sufficient preferred sizes are to be produced 82.5 % of the respondents expect that there would be high demands for precast concrete. In line with this, 80% of the respondents feel the need of producing other preferred structural elements in addition to the existing modules.

In general, it is felt that there is a need to improve the level of use of precast concrete in Ethiopia. The collected opinions indicate the measures to be taken to promote its development. Accordingly, 75% of the respondents recommend the undertaking of appropriate research to enhance its development in collaboration of technical institutions. The second recommendation is to raise public awareness by circulating information and this was forwarded by 70% of the respondents. The measures recommended are summarized in Table 3.16.

Table 3.16 Measures to be undertaken to promote the use of precast concrete in Ethiopia

Item	Measures to be undertaken	Number of marking	%
1	Improve its design and avail preferred sizes	26	65.0
2	Raise public awareness by circulating information (pamphlets, advertisement brochures. . .)	28	70.0
3	Provide the elements, cheaply through, government subsidy in order to promote the technology	14	35.0
4	Undertake appropriate research for its development in collaboration of higher technical institutions	30	75.0
5	Coordinate the designers, precasters and the end users to work together towards one end	20	50.0

Having indicated the possible measures to be undertaken, the next step was to answer the question "who should take the initiatives?", to enhance the development of precast concrete technology. Various opinions were collected from the respondents. About 55% of the respondents indicated that the Prefabricated Building Parts Production Enterprise should take the initiative to promote its technology while, 52.2% gave the priority to the cooperation of the concerned institutions (consultants, producers, and academicians) coordinated by Science and Technology Commission. The summary of the given opinions is presented in Table 3.17

**Table 3.17 Institutions who should take the initiatives to enhance
the development of precast concrete.**

Item	Institutions/organizations	Number of marking	%
1	The Government through the Ministry of Works and Urban Development	14	35.0
2	Cooperation of the concerned institutions (consultants, producers, contractors, A.A. University) coordinated by the Science and Technology commission.	21	52.5
3	The Prefabricated Building parts production Enterprise (PBPPE)	22	55.0
4	Professional associations of Engineers, architects	13	32.5
5	Investors, contractors	15	37.5
6	Any interested researcher	14	35.0

The last item considered by the survey was the special application of precast concrete other than its use for residential buildings. 95% of interviewed professionals acknowledge the use of precast concrete for the construction of bridges, poles, pipes, road side curbs and manholes. Therefore one can conclude that there is an awareness of professionals that the precast concrete technology can be used effectively for such purposes based on appropriate designs.

3.3.7 Summary and Discussion of the results

The analysis of the survey showed that there are several problems that hindered the full development and use of precast concrete technology. The major obstacles that led to the slow development of the technology are unawareness of the designers and consultants of the existing modules, lack of information on the available sizes, the level of precision required for production

and erection, and the thought that precast elements are inconvenient to install electrical and sanitary fittings which actually is not true. The IMS system adapted in Ethiopia, is considered to be non-flexible, but if additional modules are incorporated or if adequate designs are performed using even the existing modules, various design solutions can be achieved.

According to the survey results, precast concrete had certain advantages compared to the cast-in-situ concrete. The quality of the product, the speed of construction, the elimination of formworks at site and the saving of labor and construction materials are some of the merits of precast concrete. In fact precast concrete integrated with cast-in-situ concrete and reinforced concrete are the construction types recommended for Ethiopia, considering the level of construction development.

To promote the development and use of precast concrete, the cooperation of the concerned institutions and the institution in charge of its production and erection is deemed to be an indispensable. Therefore, government and non-governmental organizations in charge of technological advancement in the area should work hand-to-hand to improve the precast techniques. Furthermore, important suggestions were forwarded which indicate the immediate measures to be undertaken in order to enhance its development.

These include:

- Take measures to improve its design and avail preferred sizes in addition to the existing stock,
- To raise public awareness through the dissemination of information, advertisements, product brochures and conducting training workshops,

- To undertake appropriate research works with an involvement of higher technical institutions,
- To coordinate the designers, precasters and the end users to work together towards one end whenever it is feasible,
- Device means to use precast concrete on large projects with repetitive units for effective utilization in economic terms,
- Prepare simplified manuals, design aids and construction guidelines for the use of professionals involved in the construction industry,
- Design approach should be included in National Codes and it should be made recognized by designers emphasizing its safety, simplicity in erection, speed of construction and its economical benefit, and
- Introduce certification methods to ensure the quality control of the production to have products at an acceptable standards.

4.0 IMS, a Prefabricated Skeleton Building System

4.1 General feature

The IMS framework system of prefabricated modular elements constitutes the widely applied industrialized building technology in the former Yugoslavia. It was developed at the Institute for Testing materials of SR of Serbia from the initial idea of Prof. Branko Zezelj. The IMS system was used to build 5000 - 7000 apartments every year in Yugoslavia and its technology has been used in different countries, Italy, Hungary, Cuba, Austria, Egypt, Angola, China, Russian Federation and Ethiopia.

The IMS technology of industrial production of prefabricated members provides for:

- Cost - effective mass production of buildings,
- allow designers more freedom in shaping the space,
- low material expenditure relating to the construction of the primary structure,
- high resistance to horizontal loads (earthquakes,)

The elements of IMS may be classified into three categories depending on their function as follows.

1. **Primary, load bearing elements:** columns, floor slabs, shear walls,
2. **Secondary elements, non-load bearing elements:** cladding panels, partition walls, kitchen and bathroom units,
3. **Tertiary elements:** finishes, built equipment.

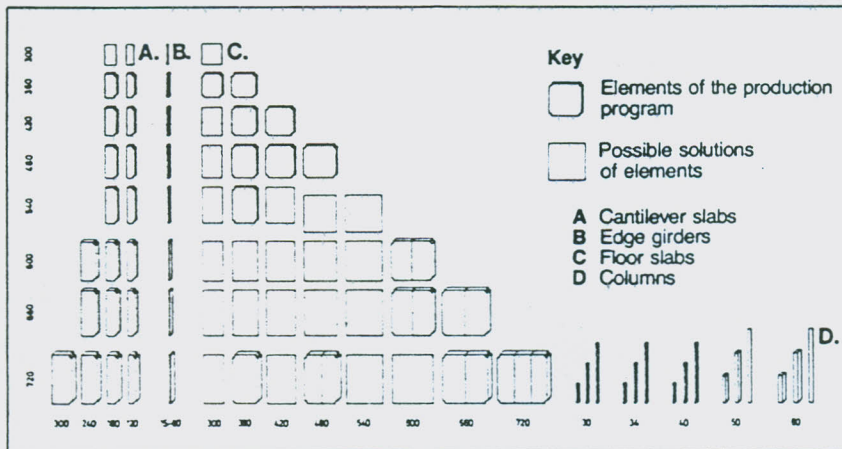
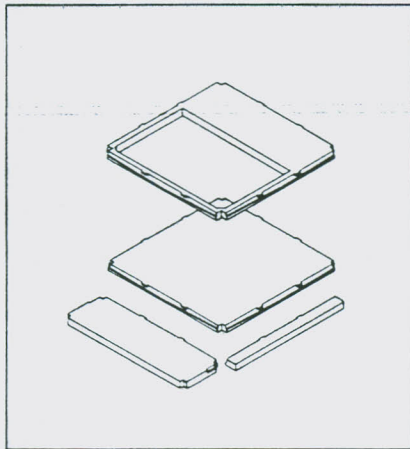
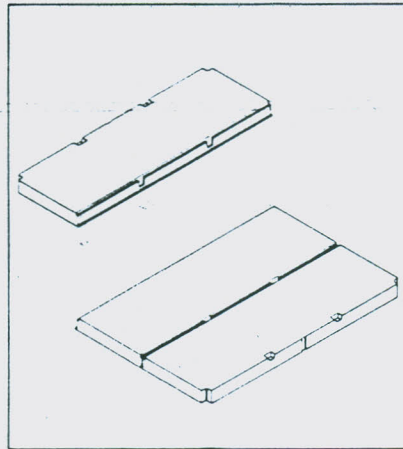


Fig. 4.1 The IMS primary element

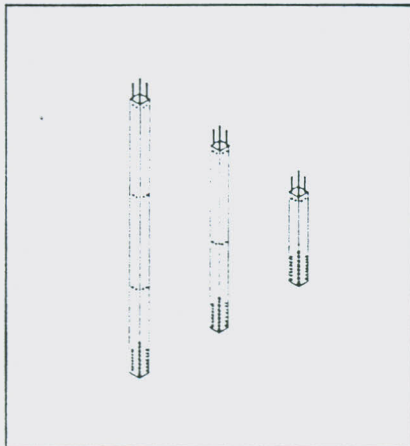
Spans and elements of the primary structure



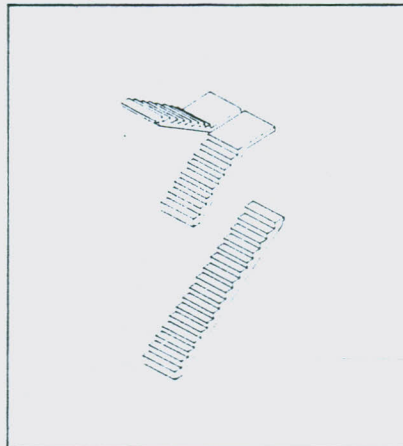
Floor slabs, cantilever slabs and edge girders



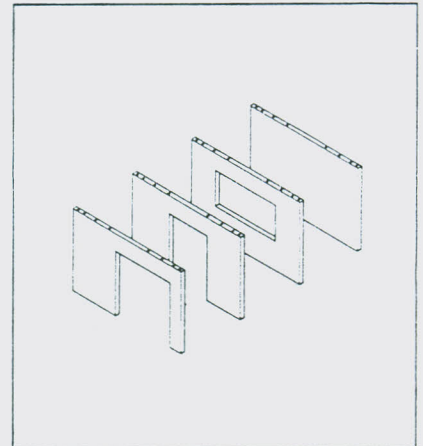
Three-segment floor slab for large spans



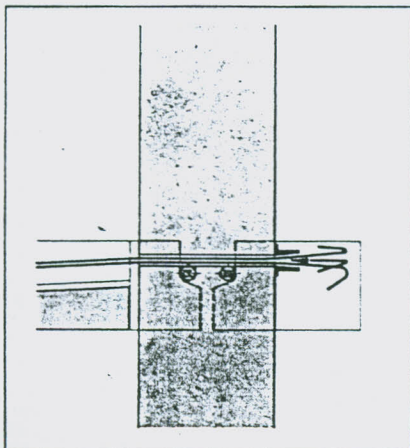
Columns



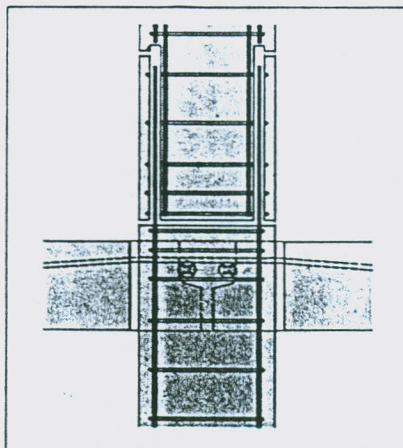
Staircases



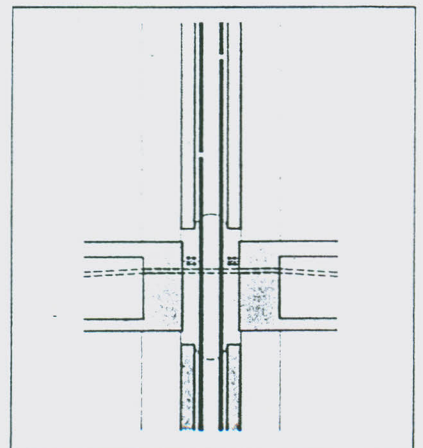
Shear walls



Joint between column and floor slab



Detail of column continuation



Joint between floor slab and shear wall

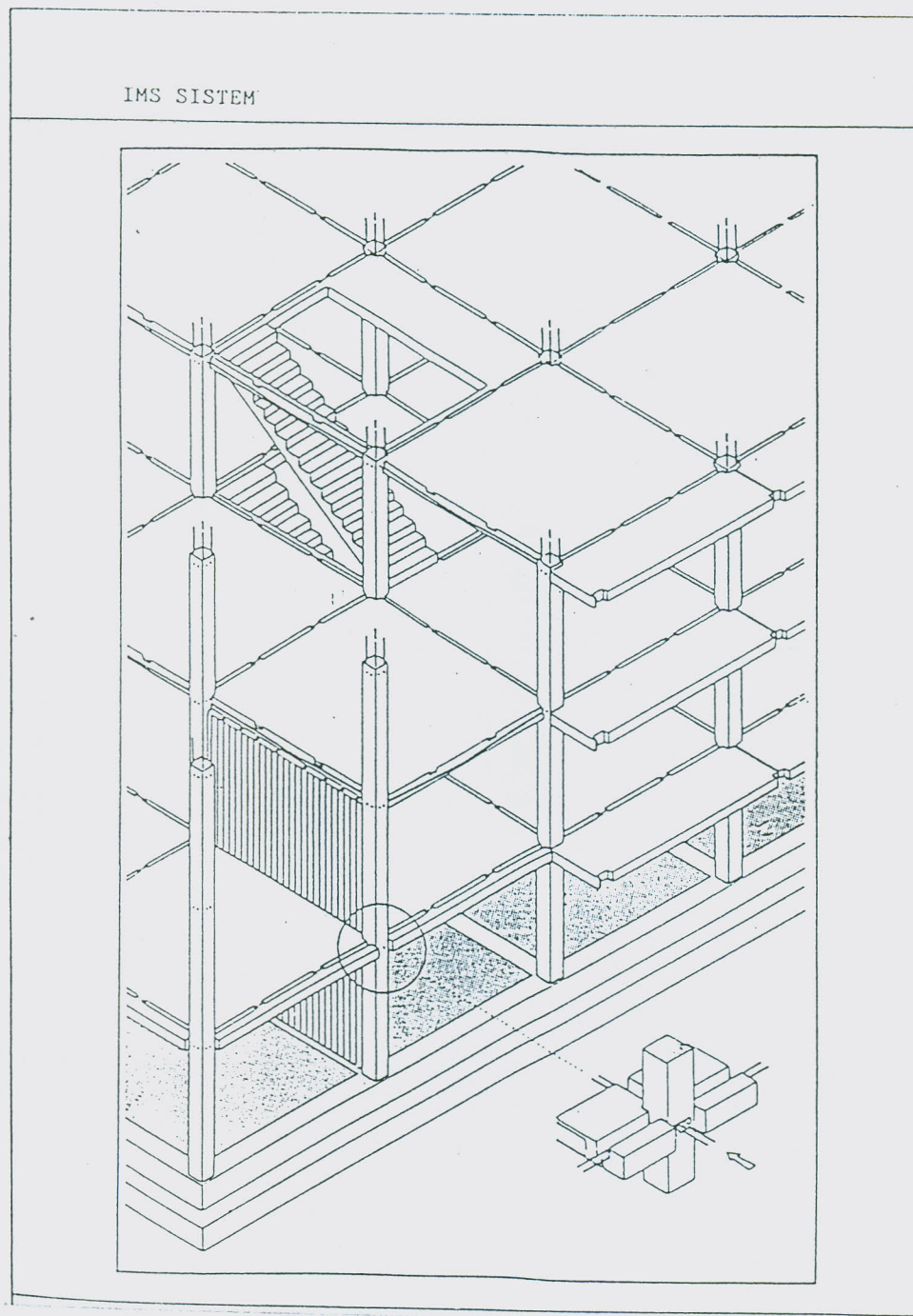


Fig. 4.2 Primary IMS structural elements assembly

All the primary elements are specific to the IMS system (see figure 4.1 and figure 4.2). They are joined by prestressing into a monolithic whole at each storey level. This makes an extremely safe and stable building, suitable for seismic zones and areas where strong winds are expected. The main advantage of this "open" modular system is that with a relatively small number of different types of elements, industrially prefabricated frameworks for a wide variety of buildings can be made. The openness of the technology also means that the framework can accommodate various sub systems, differing both in technology and materials i.e., different types of facade, partition walls and curtain walls.

The prefabrication of the primary elements may be organized on site or in standard factories of concrete elements, or in specialized plants producing only IMS system. Typical factory capacities are of 400, 750 and 1500 apartments per year. Transportation of elements can be economical up to a radius of 100km. Standard vehicles can be used for transportation. The consumption of basic raw material for a given framework is believed to be far less than any other industrial building system. (Milos, 1982)

The grid dimensions most frequently used for residential buildings are 4.20x4.20m. The consumption per square meter of gross floor area, excluding foundations, is estimated to be 0.23m³ concrete, 15.0kg of ordinary steel and 1.32kg of prestressed steel. For the same grid, the manpower input per square meter of gross area is 1.85 man-hours, for manufacture of elements and 1.35 man-hours for assembly and prestressing. (Milos, 1982).

4.2 Structural Elements

4.2.1 Primary Structural elements

The primary structural system consists of the following main elements.

- columns (one - storey, two - storey or three - storey)
- floor slabs (standard, with apertures, or cantilever)
- edge girders
- shear walls to take horizontal forces
- stair-cases

The columns and floor slabs are clenched into a monolithic whole by prestressing cables which are drawn through ducts in the columns at floor level and the duct formed between the edges of two neighboring slabs. Each floor level is clenched by a system of cables in orthogonal directions. After the prestressing the cable ducts are filled in with concrete so that the inter-storey structure becomes adhesively prestressed.

The columns in principle take only the vertical loads and the horizontal forces are taken to some extent by the frame, but for the most part by shear walls. The shear walls are placed in optimal positions between columns in order to achieve the desired rigidity of the structure. Prefabricated shear walls are commonly used except for very high buildings or high seismic areas where in-situ concrete shear walls are required.

The IMS system offers a wide range of spans (from 3.0m to 9.0m in both directions in steps of 0.60m). The floor slabs are produced in three thickness 22, 30 and 36 cm depending on weight and size. Floor slabs of greater spans are prefabricated in two or three segments which are joined later by prestressing cables. Floor slabs can be delivered with or without ceiling finishes and with appropriate openings to accommodate installations of staircases or lifts.

Cantilever floor slabs with standard overhangs (upto 3.0m) are used at the edges, but when there is no cantilever, an edge girders are required at the edges in order to give the necessary beam action and to provide ducts for the prestressing cables. Edge girders are solid cross sections that carry cladding panels.

The columns produced are most often a three-storey, square cross - section, in standard dimensions according to the span and the height of the buildings. Continuation is achieved by inserting the protruding anchoring reinforcement of one column into the corresponding holes left in the next. Shear walls are prefabricated concrete panels 15 cm thick with vertical ducts in them to be used for reinforcing bars as may be necessary to take the horizontal forces. The ducts are subsequently filled with concrete.

4.2.2 Secondary elements

The IMS system allows almost unlimited diversity of prefabricated cladding. The facade walls may be made of traditional materials, brick, hollow concrete blockets or curtain walls. The most popular has been the concrete sandwich, consisting of two concrete panels with a thermal insulator in between the two.

Cladding panels are joined to the edge girders by steel anchors which are cast in-situ. Wide variety of partition walls are available and their positioning is not restricted by structural considerations. In addition complete prefabricated kitchen or bath room walls incorporating all the necessary installations are used in the IMS system. The walls of such elements are usually thin concrete slabs.

4.3 Fabrication and assembly of elements

4.3.1 Fabrication of Elements

Elements are produced on site, at a concrete plant or in an IMS factory. They are cast in standardized steel molds which can be used about 2000 times. The concrete grade must be usually equivalent to C40.

Columns are usually cast in multiple of molds (two to four columns) at a time. The column length is three storeys for residential buildings and two stories for office buildings, ware houses etc. By inserting a partition in the mold, one-or two-storey columns can be cast. The sides of the molds can be opened and closed.

Floor slabs are cast in horizontal molds with a fixed bottom and hinged sides. There are a number of different types of floor slab, requiring different types of mold. Floor slabs with a concrete ceiling are made in two parts, with two molds: the floor slab with a coffer bottom in a coffer mold and the ceiling panel in a flat-bottomed mold. Floor slabs bigger than 4.2 x 5.4 m are made in two or three parts, which are held together by prestressing after assembly.

Staircase girders are cast in their sides in four fold or double molds. Edge girders are cast in four folds or double molds. But, Shear walls are usually cast in horizontal molds. Lengthwise ducts are left by inserting steel pipes or pneumatics shuttering in the mold before pouring and these are extracted after the concrete has laid. Shear walls can also be made in vertical steel batteries of molds.

Installation walls are cast in horizontal molds, while complete kitchen or bathroom units are manufactured by standard procedures. Such elements are not available in Ethiopia.

During the production, the molds may stay in the same place or be shifted. Among the methods available for accelerating the hardening of concrete, steam curing constitutes one of the simplest and most economical method.

4.3.2 Assembly

The assembly of IMS elements require precision and some experience in erection. Columns are assembled by inserting anchors left protruding from the foundations or the column already in position into the corresponding holes left in the bottom of the next column. The column is adjusted and temporarily held vertical by bracket props. Its position is checked with surveying instruments. The props are removed after the assembly of the next floor slab and prestressing of that floor. The floor slabs rest on steel capitals clamped to the columns during assembly and such capitals are removed after prestressing of the storey.

Shear walls are positioned between columns, over the gap between two floor slabs where the prestressing cables pass. The reinforcing bars necessary for taking additional horizontal loads can be inserted into vertical holes left in the shear walls for this purpose, and such holes are subsequently filled with concrete.

Staircases, cladding elements and other installation blocks can be assembled together with the framework or after its completion. The assembly of IMS buildings is carried out with the use of tower cranes or mobile cranes and special IMS assembly tools.

4.3.3 Prestressing

The load-bearing elements of the assembled framework are joined together by prestressing cables and strands. There are two (2x4 Ø7mm) cables in each duct used in residential buildings with a nominal force of 340 - 400 kN. The same cables are used for joining large spans of public buildings that can produce a nominal force of 600 - 800 kN. with two (2x12 Ø7mm) cables per duct depending on the span and the load.

The cables are straight at the time of prestressing. After anchoring they are forced down by special devices at one third length from each end and fixed in the designed position for heavy loads. The equipment used for prestressing, cable pressing jacks, anchor bushes and wedges and devices for driving expansion wedges are IMS patents.

4.3.4 Auxiliary appliances

During erection various auxiliary appliances are used in the mounting of individual members.

- column-reinforcement protecting appliances
- column mounting appliances
- ties or telescopic props for fixation of cantilever floor slabs.
- facing-member supporting appliances
- shear wall mounting appliance and other auxiliary equipment.

4.3.5 Production process and the output

4.3.5.1 Production

The precast concrete building parts produced currently in Ethiopia are used for three category of buildings, residential building upto 5 storey (30cm column), residential buildings upto 10 storeys (34 cm column) and public buildings (50 cm column).

The number of structural elements produced at the factory exceeds 59 considering the specific dimension of each parts. These elements can be classified according to their functions in the building as footings, columns, floor slabs, cantilevers, staircase flights, landing, edge girders, and shear walls.

The footing elements are of three types differing in dimension. These footings are used for public building, residential buildings up to 5 and 10 storeys, of course after a thorough evaluation of the soil condition of the site. If none of the three footings satisfy the governing soil conditions, then other types of footing may be recommended using the cast-in-situ method, making it compatible with precast components.

The columns available are of three cross-sectional dimension width of 30 cm, 34 cm, and 50 cm each having three variants in length, i.e., initial (363 cm), two -storey (579 cm) and 3 storey columns (869 cm).

The slabs for residential building are 420x420cm x 22 cm but there are about 4 variations. The variants are solid slab with/or without ceiling and open slab with/or without ceilings depending upon the needs of the user. The slab for public building have large dimension of 720x600x36cm but one half of it (720x300x36cm) is produced in order to minimize the weight of the element.

The cantilevers are used in conjunction with the slabs. They have different dimensions and are produced with or without ceiling. For each building category there are 8 types of cantilevers with different sizes, which brings the total number of them to 24.

There are four types of edge girders produced for each residential building with different sizes. For the public building the edge girders required are of two sizes. The edge girders are of the same type except their differing sizes.

The stairflight and landing produced can be used for the three building categories, in the same way the shear walls are used for all buildings with variations in number and locations in the building frames. Basically 3 types of shear walls are produced, one normal and the two others with openings to accommodate a window or a door. The shear walls are meant to overcome all lateral loads from seismic activities. They are produced with holes to accommodate any additional reinforcement and concrete in case the designer requires additional strength in sites with high seismic effects. The normal dimension of the shear wall is 378x262x15cm, but its concrete volume, reinforcement required and weight are variable.

The data of the elements produced at the factory are registered in a catalogue book. The catalogue book comprises of three main sections, the formwork design, drawing of reinforcements and structural details. Here, the codes of the elements, dimensions, quality specifications, reinforcements required and their spacing, details of each joints, etc. are indicated. All the managing team has to do is to check the quality of the materials used and to supervise the production process with frequent reference to the catalogue book. The catalogue book was produced by a group of Yugoslavian consultant

Engineers based on statical calculations prior to the establishment and functioning of the enterprise in 1984. Since then, no one dared to modify or to add any other design standard. It has been kept as it is for the last 13 years without any trial to redesign or improve the system.

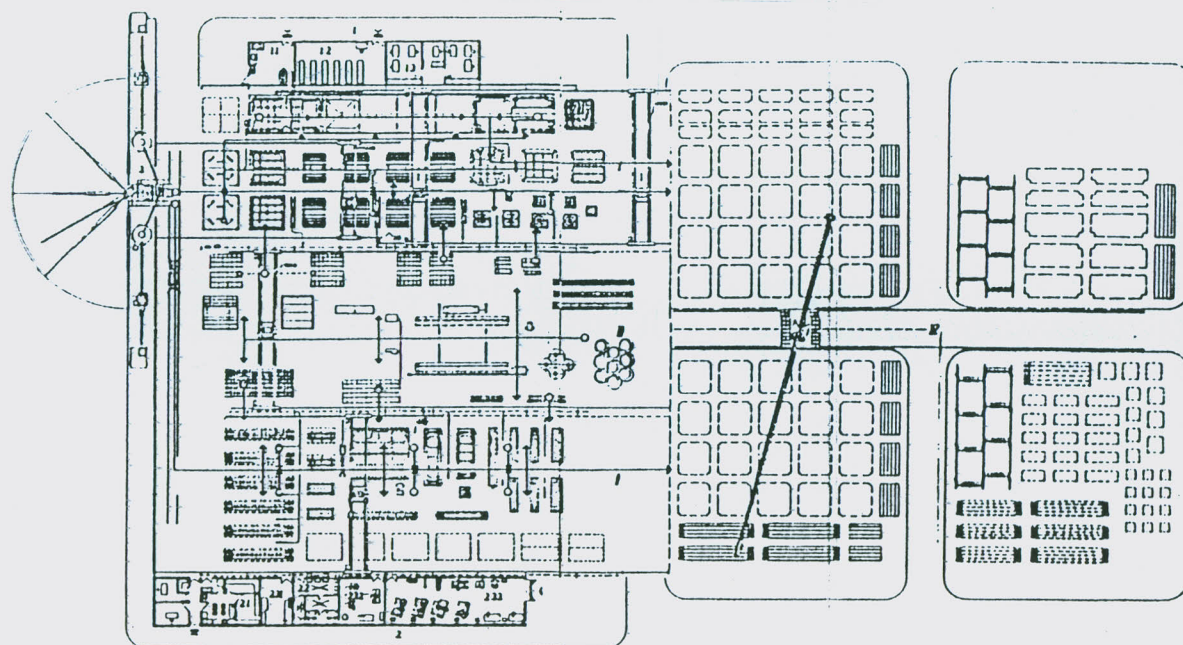
The production of members is carried out in a production hall of three bays having the overall dimension of 21.07m, 21.00m, 21.07m by 66.00m as shown in figure 4.3 and figure 4.4. The last two fields in all the three bays of the hall are uncovered and serve for depositing and removal of finished products, as well as for the delivery of reinforcement steel.

The first and third bays of the hall are arranged for the production of members in mobile and stationary steel molds. The middle bay is arranged for the production of sub-assemblies or full reinforcement assemblies. The open-air area is used for produced members storage. The factory is supplied with fresh concrete from the concrete plant situated at the face of third bay.

The production is carried out by the use of an automated concrete plant with a capacity of 18m³/h. The plant among other things contains the following equipment.

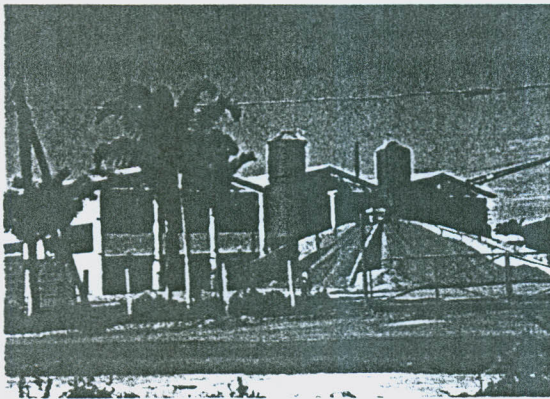
- _ Concrete mixer 500 lit per mix
- _ Water proportioning appliance, capacity 10m³/h
- _ Star-batcher
- _ Skip appliance with aggregate hopper
- _ Control cubicle
- _ Aggregate weigher, measuring range up to 1500 kg
- _ Compressor unit, 200 lit/min.
- _ Control desk
- _ Cement silo capacity 60T with dusting filter
- _ Admixture feeding appliance etc.

Fig. 4.3 PBPPE IMS Factory layout in Addis Ababa

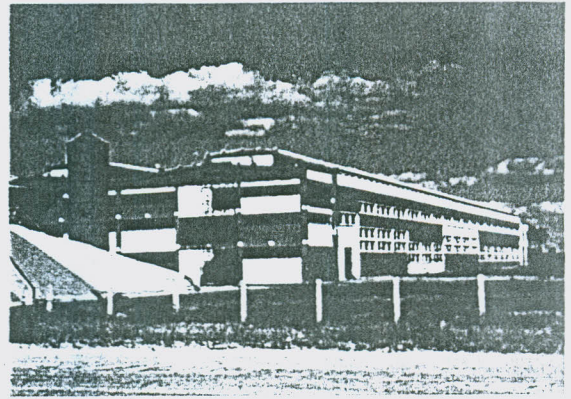


Legend

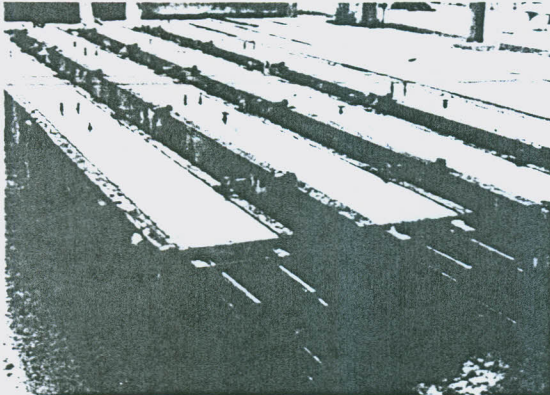
- I. Residential buildings
production of floor slabs, shear walls and foundation.
- II. Residential buildings
 - a) Production of columns, edge girders, stairs,
 - b) Public buildings production of floor slabs, columns and edge girder
- III. Steel workshop
- IV. Elements storage
 - 1. Annex I.
 - 11. Boiler houses
 - 12. Spare parts and tools storage
 - 13. Offices
 - 2. Annex II.
 - 21. Laboratory
 - 22. Sanitary room
 - 23. Workshops
 - 23.1 Electrical workshop
 - 23.2 Wooden workshop
 - 23.3 Mechanical workshop



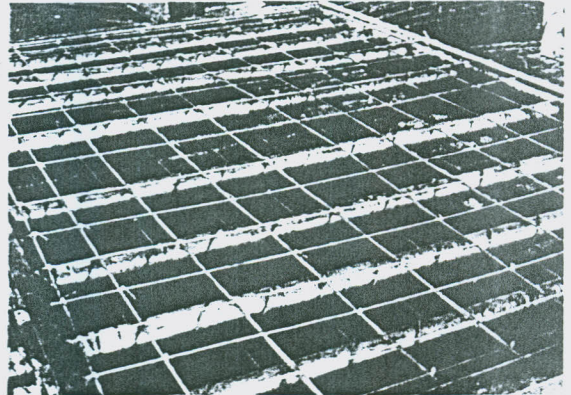
IMS factory in Santiago



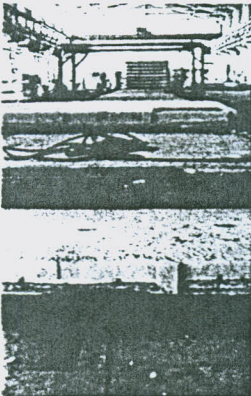
IMS factory in Cienfuegos



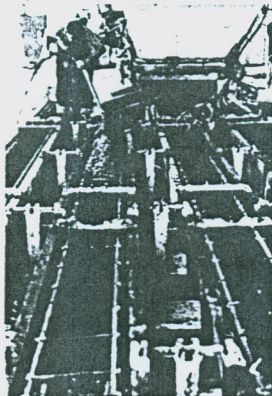
Fabrication of columns



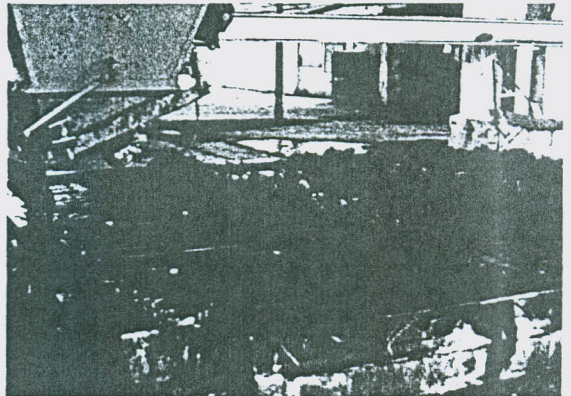
Reinforcing shear walls



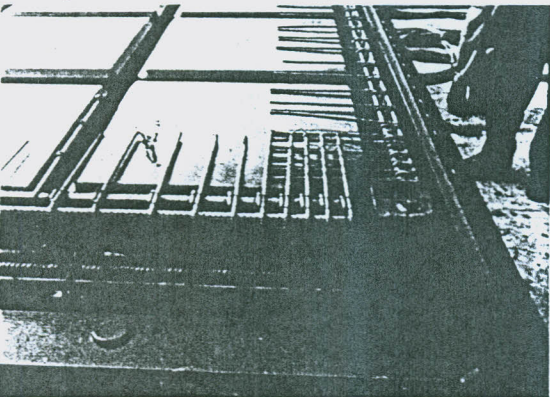
Steaming tunnel



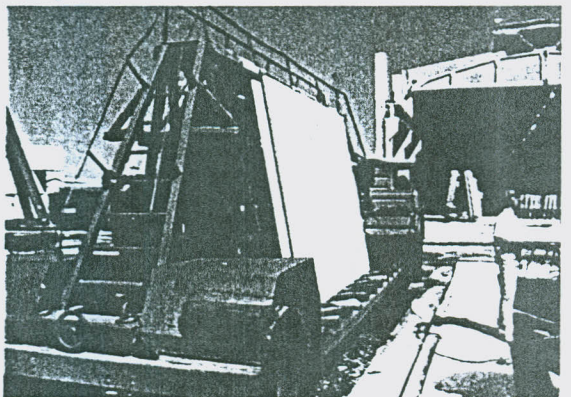
Casting columns



Casting floor slabs



Details of floor slab reinforcement



Transport of prefabricated elements

4.3.5.2 Production output

The members to be produced are defined in the catalogue of production of the enterprise. The list of the members produced in Ethiopia contains the following.

1. Floor slab 4.20 x 4.20m
2. Floor slab 4.20 x 4.20m soffit
3. Floor slab 4.20 x 4.20m with opening for lift
4. Floor slab 4.20 x 4.20m with opening for lift, soffit
5. Cantilever floor slab 4.20 x 1.20m
6. Cantilever floor slab 4.20 x 1.20m, finished on both sides
7. Cantilever floor slab 4.20 x 1.20m, right hand
8. Cantilever floor slab 4.20 x 1.20m, left hand
9. Cantilever floor slab 4.20 x 1.20m, all versions
10. Stair flight
11. Stair way floor slab (landing)
12. Column 30x30 3-floor, normal and terminal
13. Column 30x30 2-floor, normal and terminal
14. Column 30x30 1-floor, initial
15. Column 34x34 3-floor, normal and terminal
16. Column 34x34 2-floor, normal and terminal
17. Column 34x34 1-floor, initial
18. stiffening wall (shear wall) standard
19. Peripheral girder, 4.20 x 0.30m, 22 and 24 cm for columns S30/30 & S34/34
20. Peripheral girder, 4.20 x 0.38m, 22 and 24 cm for columns S30/30 & S34/34
21. Peripheral girder, 4.20 x 0.15m, 22 and 24 cm for columns S30/30 & S34/34
22. Peripheral girder, stairflight support, 22 & 24 cm for columns S30/30 and S34
23. Foundations 1.20x.20m
24. Foundations 1.60x1.60m

25. Foundations 2.0x2.0m
26. Floor slab 6.00x7.20m
27. Cantilever floor slab 2.00 x 6.0m
28. Cantilever floor slab 2.0 x 6.0m, finished on both sides
29. Cantilever floor slab 2.0 x 6.0m, right hand
30. Cantilever floor slab 2.0 x 6.0m, left hand
31. Cantilever floor slab 2.0 x 7.20m,
32. Cantilever floor slab 2.0 x 7.20m, finished on both sides
33. Cantilever floor slab 2.0 x 7.20m, right hand
34. Cantilever floor slab 2.0 x 7.20m, left hand
35. Column 50x50 cm, 2-floor, normal and terminal
36. Column 50x50 cm, 1-floor initial and terminal
37. Peripheral girder 6.00 x 0.40m normal and atrium-type
38. Peripheral girder 7.20 x 0.40m normal and atrium - type

4.3.6 Basic considerations

The complete structure of the prefabricated IMS skeleton system made of prestressed concrete consists mainly of columns, floor slabs (normal & cantilever) shear walls, stair ways, peripheral girders and other units. All members:

- are fabricated in standardized steel molds,
- are of high-quality concrete of C40,
- are cured by rapid hardening procedure so that the molds can be used once or twice in the course of daily cycle,
- can be produced in a well-organized concrete plants or on the building sites,
- The members are transported to the site in horizontal position by ordinary trucks. Large sizes are usually fabricated in two parts for easier transportation and linked up on the site, prior to mounting most frequently by prestressing.

- In case of multi-storey buildings, the prefabricated members are mounted with the aid of tower cranes, while truck-cranes can be used in the case of lower buildings. It all depends on both the size and the weight of individual members, or the over-all size of the system involved.
- The prefabricated prestressed concrete skeleton system has all the characteristics of monolithic skeleton system and gives the designer broad opportunities and freedom in shaping the building layout. The arrangement of structural members to the largest possible extent results from architectural program and functional design of the building. It is believed that the system imposes a very small number of limitations. Basically the designs under the IMS system takes into consideration the following points.
- The design should adapt the basic plan to the design assignment and town-planning conditions.
- In structural aspects, it is desirable to achieve symmetry in both directions, though not mandatory.
- Asymmetry in the arrangement of partition walls and stairways is permitted while the arrangement of shear walls should be as symmetrical as possible in areas of high seismic activity.
- The height of a building to be constructed depends on the same parameters applied to the buildings with monolithic reinforced concrete system.
- Joints under the IMS are considered with the same principles as those applicable to conventional reinforced concrete skeleton building.
- The position of expansion joints depends on soil conditions, shape of building and its length. The longest buildings constructed so far were about 80m long and 26 floors high.
- Buildings of versatile layout and different number of floors can be built to have suitable shape of accommodation space in accordance with the latest trends and developments in function.
- Interior variability of the premises by using light-weight dismountable partition walls is possible to match to the possible changes in the family structure.

4.4 Design Principles

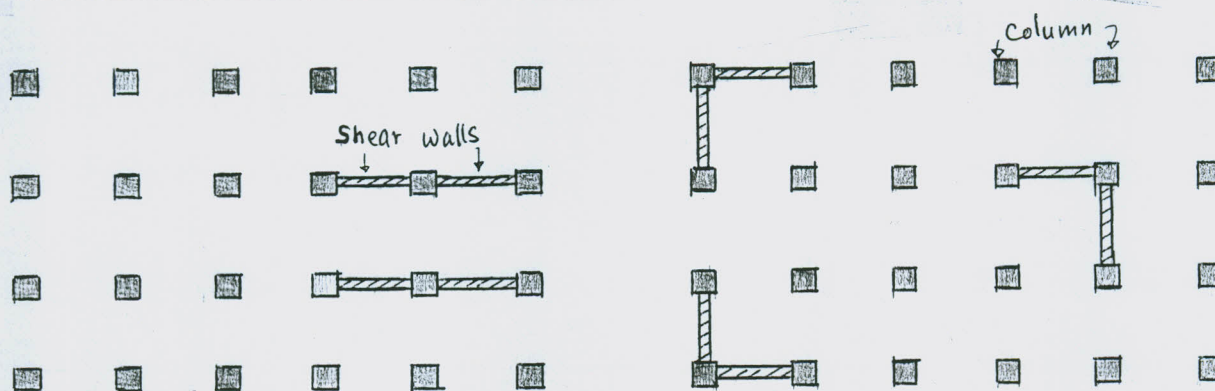
The Design of the IMS system has relatively limited number of conditions to adhere to for static safety and its rationality. These are the characteristics of prefabricated skeleton systems. There are a lot of building design options in IMS system depending on the required program and terrain characteristics.

4.4.1 Static design requirements

The static design requirements taken into consideration are similar to the conventional monolithic cast in situ concrete depending on the design task, functions to be met and the urbanistic conditions. Some of the requirements are:

- Support structures should be made of columns with girders between them on the accepted span.
- Openings with bigger dimensions must be placed so as not to interrupt either columns or girders.
- Columns must be continuous along the whole height of the building.
- The general building layout should meet the optimal requirements, the static stability and safety of the building.
- The scheme should be axially symmetrical in its longitudinal and transversal direction in relation to the number of fields and shear wall arrangements.
- Shear walls are used as primary supporting elements to carry all the horizontal forces. Shear walls should be placed axially symmetrical in building layout for longitudinal and transversal directions. The arrangement of the shear walls along the edges is considered to be favorable as it provides the best resistance to torsional moments. Figure 4.5 shows some of the shear wall arrangements in the layout.

Figure 4.5 Shear wall arrangements



4.4.2 Technological Conditions

The main technological conditions required for the IMS system are the following.

- Weight of each elements; (the heaviest elements for dwellings are approximately 40 kN.),
- bearing capacity of each element,
- Layout of the building should be chosen so that disposable cranes can access to the building from a chosen location,
- For normal dwelling houses cranes of approximately 1000 kN-m capacity can overcome all the difficulties,
- Number of various elements forming the structure of a building should be optimal with minimum number of different molds if possible,
- When the designer decides for solutions that require new types of elements, one should bear in mind the fact that such elements, may be produced in the already existing molds with minimum changes.

4.5 Design of residential buildings

4.5.1 Structural Span

Based on the analyses and suggestions of reputable Belgrade architects (IMS manual) the preferred span with regard to functional application of the system in dwelling construction, and on the basis of production and erection means (weight of elements), the application of the structural span of 4.20 x 4.20m. was proposed in 1958. Since then, the 4.20x 4.20m span has been used for the construction of several apartment flats and nowadays it is one of the applied spans in the IMS system.

Generally the selection of structural spans for architectural application takes into account some basic concepts which include some of the following.

- to enable construction of 4 to 20 or more storey dwelling buildings,
- to meet all the requirements of urban practice regarding the horizontal and vertical overall dimension.
- to enable the largest possible variety of solutions, with the smallest possible variety of structural elements.
- to enable the application of all necessary dwelling solutions based on the existing regulations.

Accordingly, the selection and application of 4.20m x 4.20m span in various countries, as well as in Ethiopia, has given the following benefits:

- Its size and weight (4 to 5 tons) corresponds to the available standard type cranes,
- It is proved to be very convenient for architectural space forming,

- The effective area of the span is between 15 and 18m² which corresponds to small dining rooms or big parents room which can be divided into two areas with 8 to 9m² as per any future requirements,
- Cantilever floor slabs of 4.20 x 1.20m can be used (and are still in use) to facilitate the expansion of the area within the span as a covered space or as a balcony-open space or both combined.

4.5.2 Horizontal overall dimensions

The horizontal overall dimensions of dwelling buildings should follow the standards and pertinent regulations for residential areas. This includes the character and locations of staircases the number of flats that use the staircases and the possible number of flats in relation to the width of facade. It is believed that two flats on one staircase where both flats have two facades, constitutes a very convenient solution in the arrangement of horizontal dimensioning. Naturally this leads to a formation of typical flats or "blocks" that may be repeated elsewhere.

In any case, the arrangement of dwelling flats is based on the IMS technology, the terrain characteristics, the effective urban regulations and cultural needs of the inhabitants of that locality. Consequently, there are various solutions being applied using 4.20 x 4.20m span alone in different situations.

4.6 Calculation of Structural Elements

4.6.1 Gravity Loads

The statical calculation of precast/prestressed concrete in the IMS structures has all the characteristics of a common reinforced concrete frame structures with an additional calculation for prestressing and its influences. It incorporates calculations of the structure at all stages which can occur during the construction.

The statical calculations involved can be summarized for major structural elements as follows.

4.6.1.1 Floor slabs

The IMS floor-slabs are box type slabs with three internal ribs in both directions and thin upper and lower plates. The edge beams of the slab form edge girders in the assembled skeleton structure.

The floor slabs are usually calculated as a grillage of reinforced concrete beams in two stages. At first calculation, the floor slab is considered as a grillage of simply supported beam loaded by its own weight. In the second stage, it is assumed that the grillage is a system of beams with built-in, rotationally fixed ends. At this stage the cross-sections of the edge beams are increased with the cross-section of concrete for the cable protection, cast in situ after the assembly of the floor slabs. Finally the total bending moments and shear forces are the sum of the corresponding calculated values at each stage.

Floor slabs with large openings for lifts or staircases and cantilever floor slabs have to be calculated in the same way as normal floor slabs. Cantilever

floor slabs are connected to the frames at two points unlike the normal slab which is connected to the frame at four points. They are considered as ribbed plates and the calculation can be performed in the same principle.

4.6.1.2 Edge girders

Edge girders together with adjacent external ribs of floor slab, constitute the girders of outer frames. Therefore, they form part of the main frame and their calculation is carried out with the main frame. If the girders are slender type, then a stability (buckling) analysis should be checked.

4.6.1.3 Columns

Axial forces in any column depend on the column position and the number of storeys of the building, therefore, columns statistical calculations are carried out for each case. The typical load analysis for columns considers the self weight of the column, dead weight and live load carried by all floor slabs above the considered column. The maximum and minimum axial force for any column at any storey can be obtained from such analysis. The bending moments are obtained from typical frame calculations which takes into consideration the dead and live loads as well as the prestressing forces of the cables.

The analysis can be carried out using a permissible stresses method, or an interaction of N-M or "limit state" diagram which depends on the cross-section and the quality of the materials used.

4.6.1.4 Foundations and staircases

Calculations for foundations and staircases require no special instruction. The calculation for foundation depends on the type of foundation used and the soil parameters. For staircases, the stairflights are treated as a simply supported reinforced concrete beams.

4.6.2 Horizontal loads

In the IMS building system the frame structure is stiffened by reinforced concrete shear walls. The frames are designed to carry all the vertical loads and approximately only 10% of the horizontal forces. The resistance of about 90% of the horizontal forces are considered to be beard by the shear walls.

Horizontal forces to be taken into consideration are seismic or wind forces independently and non-simultaneously. Their intensity is defined by national codes, which indicates the calculation procedures.

For the IMS building, the free oscillation period, (T) of the building required for seismic force calculations can the approximated as:

$$T = 1.79 H^2 \sqrt{m/EI} \quad (\text{IMS, Technical document Book 1.2})$$

Where :

- H = is height of the building
- m = mass of the building per height (uniformly distributed)
- E = modulus of Elasticity.
- I = moments of inertia of all shear walls.

The calculations of the structure for horizontal forces can be done by an exact or approximate methods. In an approximate method all horizontal forces

are carried by the shear walls. The total bending moments and shear forces, caused by the horizontal forces are distributed to the shear walls, proportionally to their moments of inertia.

The shear walls are designed and reinforced to carry the bending moments and shear forces as per the outcome of the calculations. An exact calculation of the horizontal forces requires the use of computers with software for such purpose and there are several program in use today.

The load bearing capacity of shear walls can be calculated by the limit state method. The ultimate transversal force which acts with the ultimate bending moment must be fully covered with the horizontal reinforcement. In addition, to strengthen the shear walls, the load bearing capacity of the shear wall foundation must be at least 10% greater than the load bearing capacity of the shear walls in order to account for possible soil deformations.

4.6.3 Dynamic analysis

Especially important buildings can be analyzed by direct dynamic analysis using recorded accelerograms. The dynamic analysis method is not a standard treatment of the IMS buildings and it is used only in exceptional cases.

5.0 IMS for Low Rise Buildings

5.1 Design Brief

Recently, it has become clear that Regional Governments focus on the development of high rise buildings and low rise residential buildings on a relatively small plot areas rather than villa houses. The IMS system has been applied significantly for relatively high rise buildings. The purpose of this chapter is to introduce the IMS system primarily for low rise G+1 dwelling buildings. If certain housing topologies are used on small plots it could be cost effective in economic terms for urban infrastructure development such as access roads, water supply schemes and power supply.

In view of this assumption, the proposal forwards schematic urban layout of low rise dwelling buildings and finally selects one plot layout arrangement for further elaboration. The selection of the said layout does not mean that it is the best arrangement for all cases, because the layout of a building can be dictated by the topography and town planning requirements.

5.2 Site Planning

The IMS prefabricated concrete frame, once assembled and prestressed has all the properties of a traditionally built concrete frame structure, so it offers wide scope of choices in planning. The basic concept in the design and use of IMS is that the over all configuration should be adjusted to satisfy the design and town planning requirements. Different design alternatives can be quickly assessed and the best one chosen, if there is an efficient organization of designs. Such organization establishes procedures of standard designs, prepares catalogues for various elements and computer aided data processing techniques.

Various spatial arrangements can be done according to the needs of the community. In fact, this depends on:

- _ The terrain characteristics,
- _ specific needs of the future occupants,
- _ town planning requirements of the specific locality and the guidelines of the master plan,
- _ aesthetic view of the building structures,
- _ structural and architectural requirements,
- _ specific sizes alignments and junctions of roads,
- _ urban infrastructure requirements,
- _ supply of developed land.

For instance, based on the above mentioned requirements possible spatial arrangements can be made as shown in figure 5.1.

Various building layouts can be organized from the 4.20 x 4.20 m IMS system. From the various possible arrangements, Figure 5.2b was chosen for a G +1 building model and a structural analysis was performed in the sub-chapter to follow.

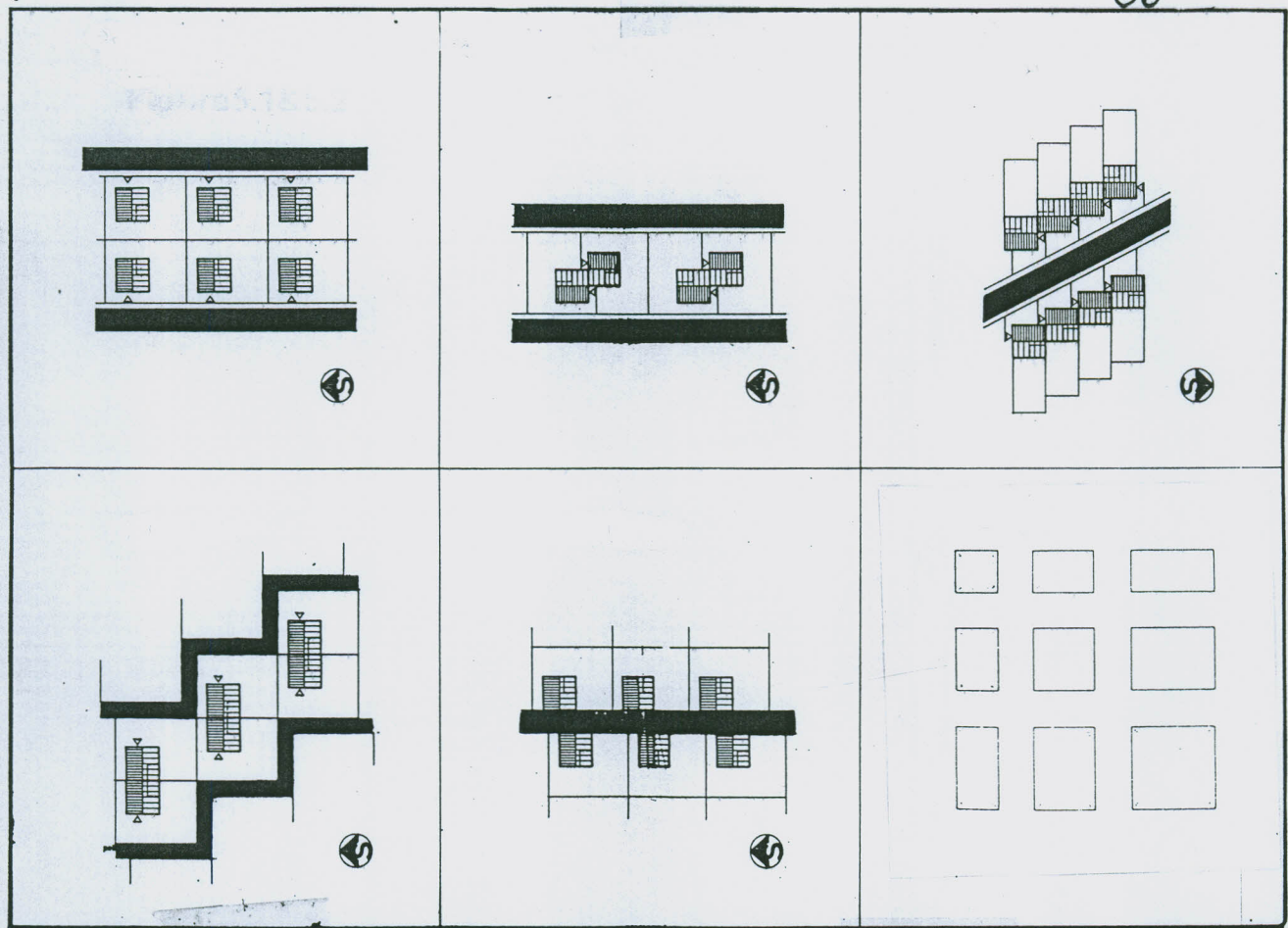


Figure 5.1 Possible spatial arrangements

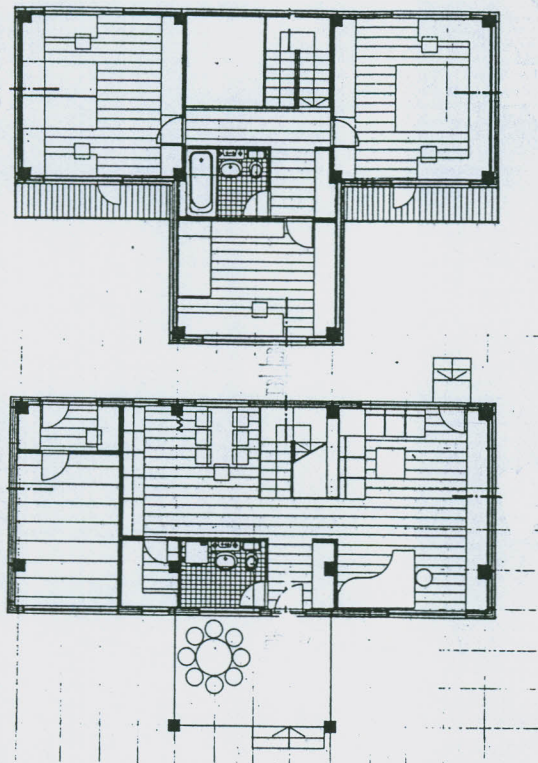


Fig. 5.2a

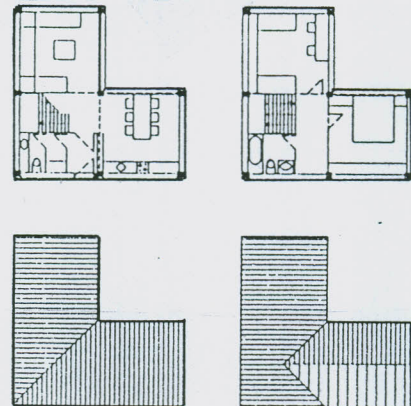


Fig. 5.2b

Figure 5.2 Possible building layout

5.3 Structural Span

The span of 4.2m x 4.2m square floor slab has proven to be the most widely used structural span. This span was chosen for the present work because of the following points.

- _ to use the existing mold with minimum changes,
- _ variety of structural solutions can be achieved,
- _ its size and weight are relatively light enough to be handled by truck cranes for transportation and during erection,
- _ the effective area of the span corresponds to the needs of the majority of urban dwellers,
- _ the experiences so far gained in the production and assembly of the span is considerable,

In addition the guidelines for accommodation requirements and minimum space standards (NUPI, 1989) states that the minimum space requirements is 6m² for cooking, 2m² for sanitation, 12m² for living and eating and 10m² for sleeping for low income groups. This being the minimum requirements, one can prepare design solutions that encompasses different accommodation areas at ground floor and ground plus one low rise storeys. Physical areas of 4.20m span floors can extend 1.20 m using cantilever floor slabs in case of big family requirements. The plot arrangements can be made to be built as duplex units or detached from one another, but closely placed together in order to save the surrounding area for circulation.

5.4 Low rise building modules

To propose new modules of precast concrete elements the following points were taken into consideration.

- capacity of the existing structural elements,
- appropriateness of the existing elements for low-rise buildings,
- use of the existing molds with minimum modification and or changes,
- integrity of the new modules with the existing modules,
- preferences or the frequently used size of reinforced concrete structural spans,
- the possible number of repetitions of the proposed modules,
- the cost of new molds as compared to the cost for the modification of the existing molds
- types of residential buildings mostly constructed currently by individuals
- the trends followed by the emerging real state developing private enterprises

5.4.1 Proposed Modules

It was felt that forwarding different modular sizes is not a hard task. But, such proposal alone can help a little in the promotion of precasting techniques unless supported by a dedicated housing development program. So, instead of forwarding various alternatives, a workable sizes were selected and proposed based on technical feasibility and needs of the majority of urban dwellers.

The suggested modules are:

1. Floor slab size: 4.20 x 4.20m with slight modification
2. Column cross-section: 25 x 25cm (length 1-storey and 2-storey)
3. Edge girder of 17cm width and 386cm length
4. Stair case and landing (cast in-situ)
5. Footing 1.20x1.20m footing or cast-in-situ as the soil properties may dictate

5.4.2 The assembly of the modules

The suggested modules were put together to form the design of a ground plus-one storey building with all facilities for a medium level citizen. The layout of the building is as shown in figure 5.3

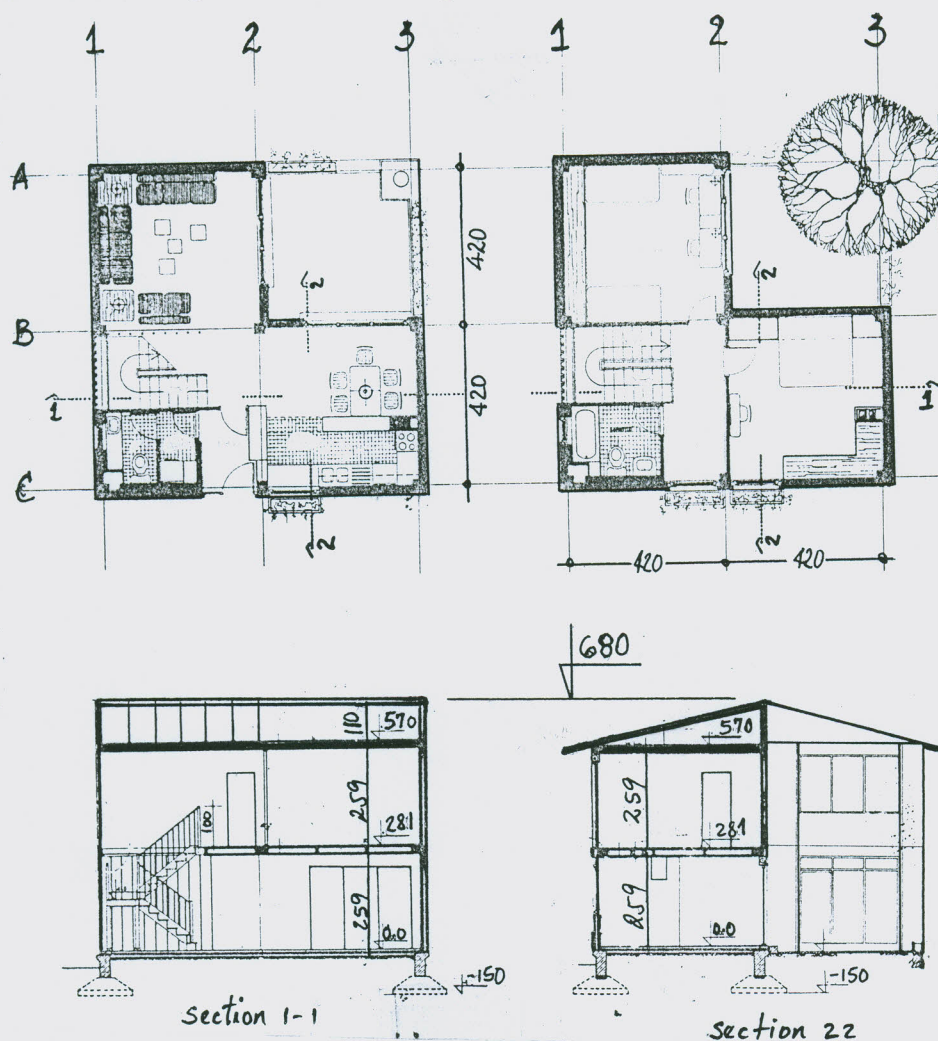


Figure 5.3 Proposed model of the low rise G + 1 building.

The total requirement of the prefabricated elements of the building is as given in Table 5.1.

Table 5.1 Specification of elements

No.	Elements	Code	Required Number	Remark
1	Footing	F	8	cast -in-situ or from the available precast sizes
2	initial column	C1	8	
3	Column	C2	8	
4	Slab	S1	2	
5	Slab with hole	S2	1	
6	Edge girder	EG	8	
7	Stair flight	SF1	1	
8	Stair flight	SF2	1	
9	Landing	LN1	1	
10	Grade beam	GB	16	

Footing

One of the precast standard footings or cast-in-situ could be used depending on the outcome of structural calculation as well as soil condition. If cast-in-situ footing is to be used physical shape of the footing should be prepared in such a way that it can be easily assembled with the precast initial foundation column.

Columns.

Columns of 25x25cm cross-section are proposed for the low rise buildings. The columns are initial columns and one or two storey columns. The length of initial columns depend upon the soil characteristics below the ground level, for this work an initial column of 1.50m is used. One - storey or two storey standard columns length are to be used for the rest of the work. The dimensions, reinforcements and schedules of reinforcements are as given in figure 5.4. The length of the column is 2.70m for one-storey building and 5.40m for 2 storey column. Details for anchor support, holes for cables have to be worked out.

Floor slabs

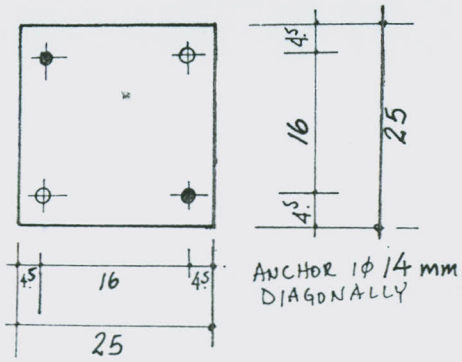
Standard floor slabs and slab with hole are to be used with modifications at the edges to accommodate the assembly with the selected columns sizes. The details of the slabs are given figures 5.5. the length of edges of the slab has to be adjusted to fit to the 25x25cm column. (i.e. $k = 14.5\text{cm}$ $a = 5.5\text{cm}$).

Edge girders

Standard edge girder of 17cm is to be used with slight modification in size. The 17cm edge girder is lighter than other edge girders and it can be finished flush with the columns. The length of edge girder has to be adjusted to accommodate the 25x25cm column. Its length is increased to 386cm.

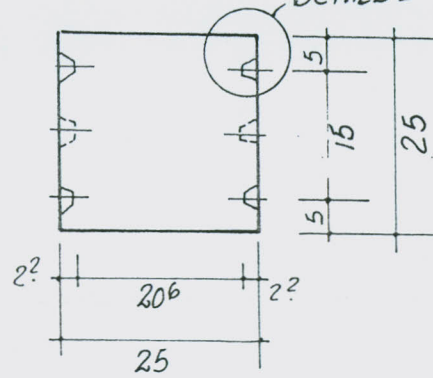
SECTION I-I

Holes $\phi 30\text{mm}$ DIAGONALLY



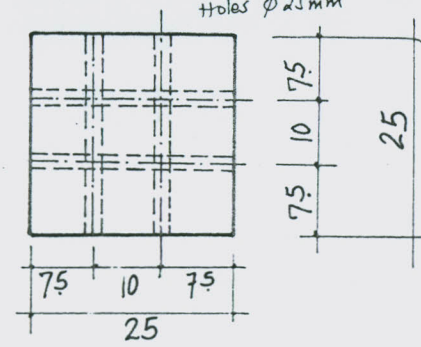
SECTION II-II

DETAIL 1



SECTION III-III

Holes $\phi 25\text{mm}$



DETAIL 1.

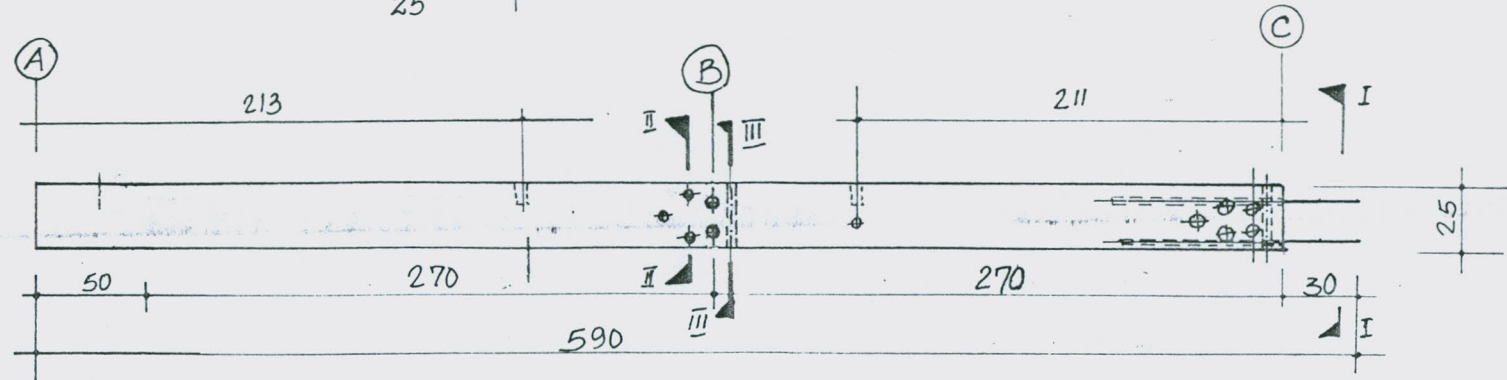
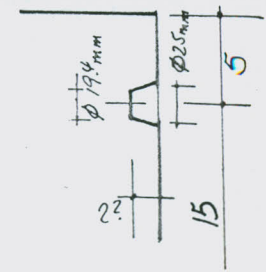
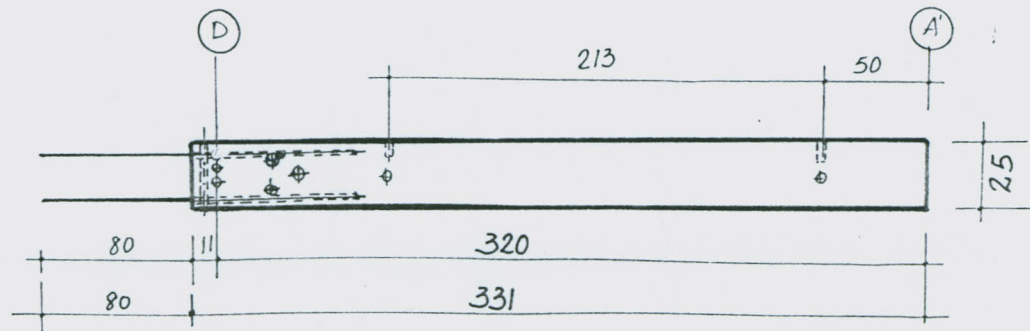


Figure 5.4 25x25cm column



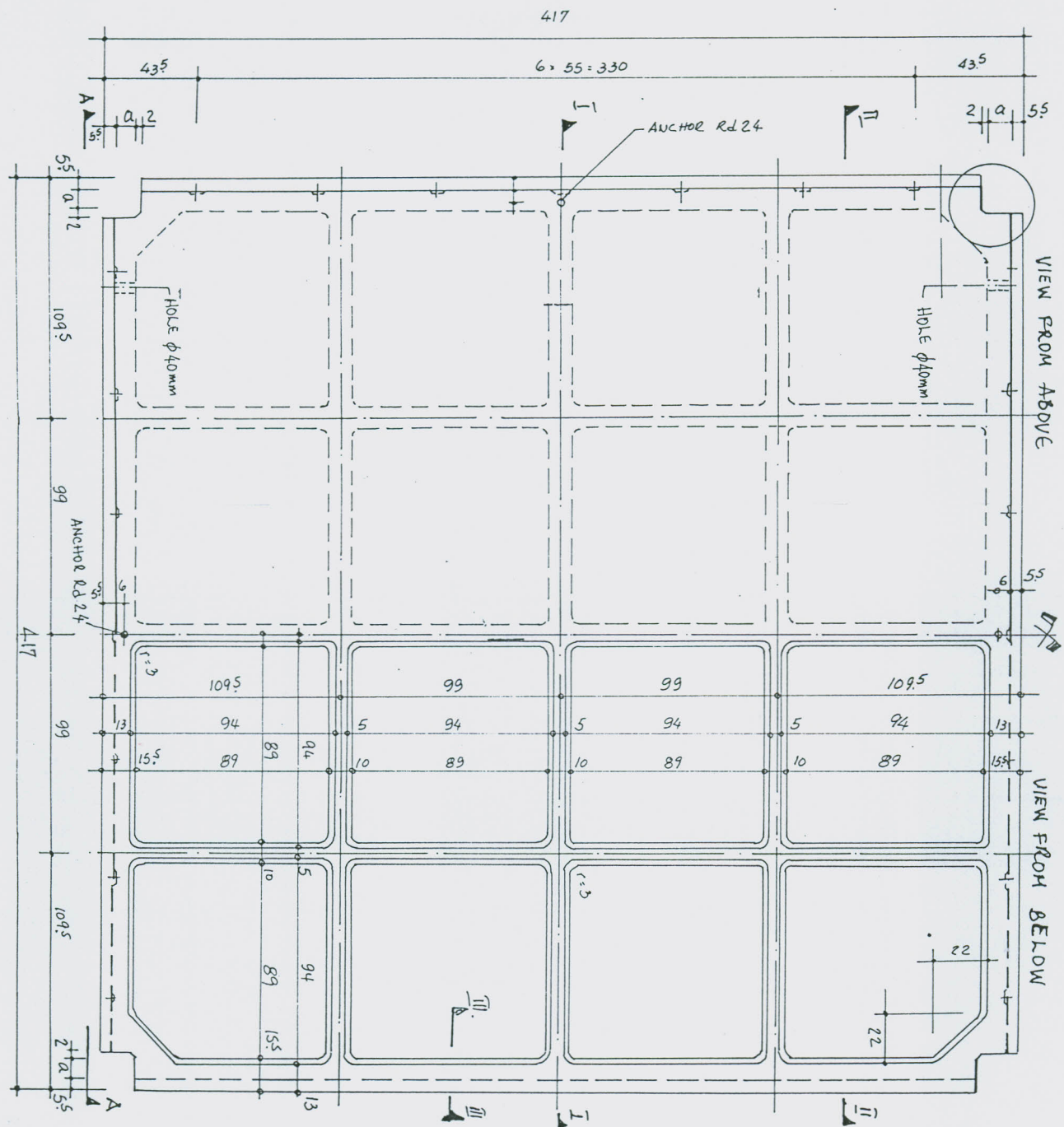


Figure 5.5 Normal 4.20x4.20m floor Slab.

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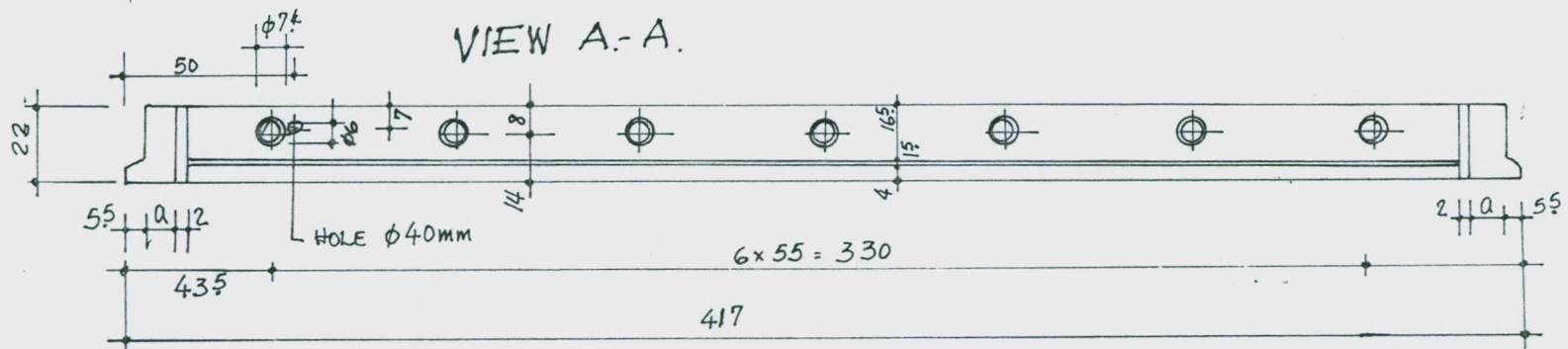
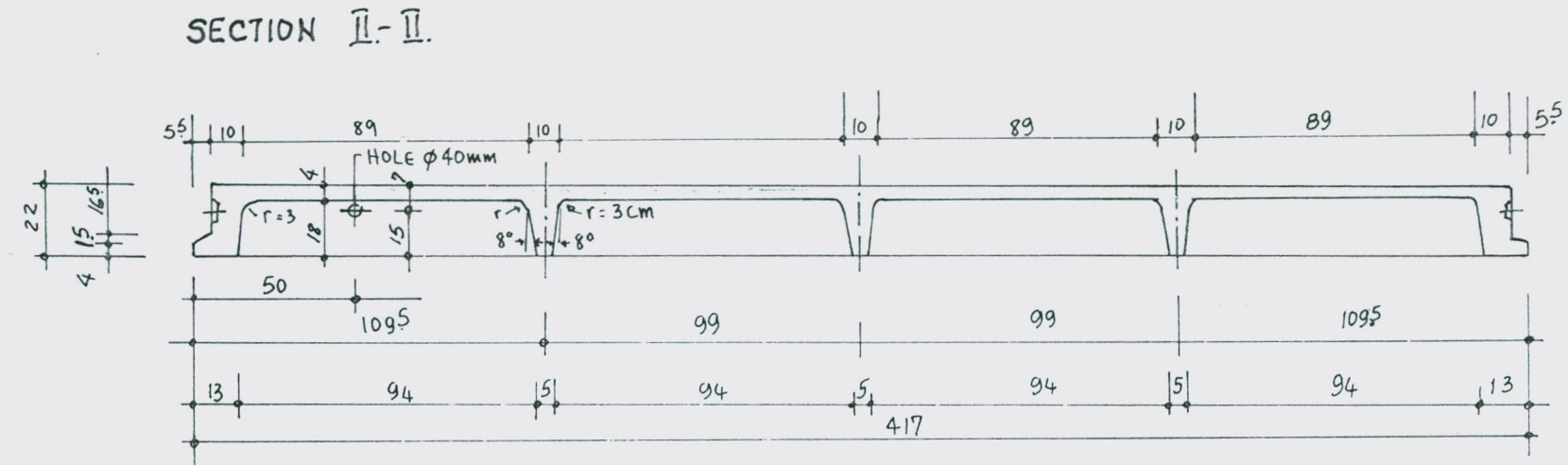
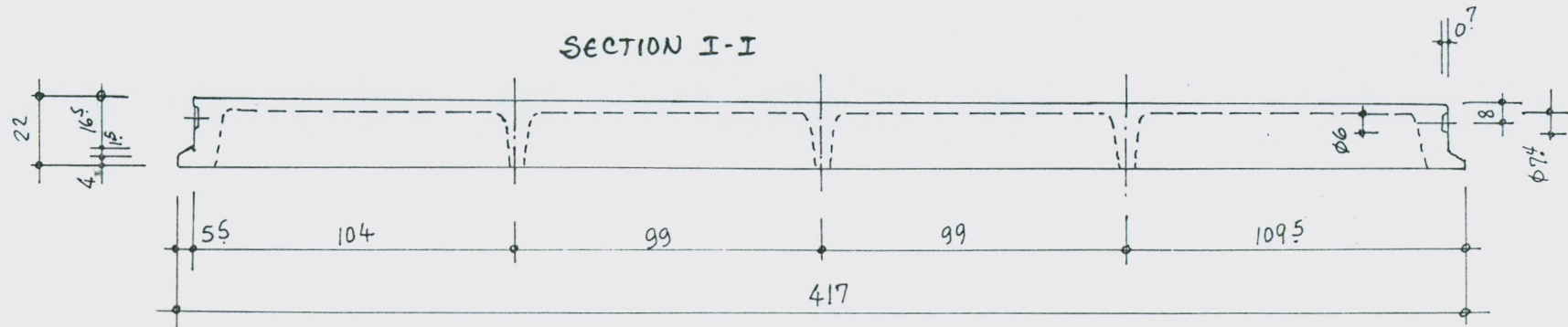


Figure 5.5b Normal 4.20x4.20m floor slab sections

Cast-in-situ combination

The upper tie beam, the grade beam and the ground floor mass concrete works are to be executed through the conventional concreting system. The roof works are conventional cast iron sheets with wooden truss. The infill wall material choice depends upon the interests of the future occupant of the dwelling. For the present case brick walling material is selected.

The available standards stair case and landing of the IMS precast system occupies the whole span area bounded by 4.20x4.20m. But for the low rise G+1 building depending on the traffic intensity, a space bounded by 2.00x2.60m area can suffice, so, cast-in-situ stair case and landing is proposed in the present work.

5.4.3 Vertical Loads of the building

Basic data on the building are summarized as follows. The Ethiopian standard code of 1983 was used throughout the work.

- . wooden truss span 8.40m.
- . Roof angle $\alpha = \tan^{-1}(1.10/4.20) = 14.7^\circ < 15^\circ$
- . Center to Center spacing of truss = 1.3m.
- . number of truss required = $8.4/1.3 = 6.5 \Rightarrow 7$ trusses.
- . Spacing of purlin 90 cm center to center, and 7 rows of purlin required.
- . length of upper truss chord = $4.34 + \text{over hang } (0.6\text{m}) = 4.94\text{m}$
- . column c/c height = 2.70m.
- . clear span height = $2.70 - 0.11$ (half slab) = 2.59m.
- . Total height of the building $2(2.70)+0.3+1.10= 6.80\text{m}$

Take the load intensity of:

- cast iron sheets = 0.05 KPa
- purlin = 0.1 kN/m

- Truss = 0.1 kN/m
- Q_k (live load) = 0.5 KPa (for roof slopes upto 15°)
or Q_k = 0.9 kN concentrated load.

Conditions of the building layout.

- a) regular in plan
- b) overall height = 6.8m < 30.0m
- c) overall height / least plan dimension = $6.80/4.20 = 1.6 < 4.0$

Wind pressure $P_z = (C_{pe} - C_{pi}) q_z$

q_z = 0.504 for 6.8m height by interpolation

C_{pe} = -0.83 for wind ward and -0.5 for leeward for a slope of 14.67° by interpolation.

C_{pi} = +0.2 for wind normal to permeable wall.

The wind force P_z = - 0.519 KPa wind ward

= - 0.353 KPa Leeward

Loads on purlin

Dead load (G_k) = $0.05 \times 0.9 + 0.1 = 0.15$ kN/m

Live load (Q_k) = $0.5 \times 0.9 = 0.45$ kN/m or
= 0.90 kN (concentrated)

wind load (W_k) = $-0.519 \times 0.9 = -0.47$ kN/m

Load combination for limit state design

1. $1.3G_k + 1.6Q_k = 1.3 \times 0.15 + 1.6 \times 0.45 = 0.92$ kN/m
2. $1.3G_k + 1.6Q_k$ (conce.) = $1.3 \times 0.25 + 1.6 \times 0.9 = 0.33$ kN/m + 1.44 kN
3. $0.8 (1.3G_k + 1.6Q_k + 1.6W_k) = 0.8 [(1.3 \times 0.25) + (1.6 \times 0.45) - (1.6 \times 0.47)]$
= 0.24 kN/m

Check the critical cases

- case 1. Uniformly distributed load of 0.92 kN/m
- case 2. Uniformly distributed load of 0.33 kN/m and 1.44 kN concentrated load
- case 3. Wind load uniformly distributed load of 0.24 kN/m.

Moment distribution method was used to obtain the shear forces and the bending moments. Accordingly,

case 1.

$M_{\max} = 0.22 \text{ kN-m}$ and $R_{\max} = 1.66 \text{ kN}$

Reactions at the ends of truss = 11.50kN.

case 2.

$M_{\max} = 0.39 \text{ kN-m}$ and $R_{\max} = 2.25 \text{ kN}$.

External truss reactions = 15.66 kN.

Case 3 is not critical

$\therefore$ Case 2 governs, $M_{\max} = 0.39 \text{ kN-m}$ and $R_{\max} = 2.25 \text{ kN}$ The design of the purlin can be carried out using the obtained maximum values.

Loads transfer from floor panels.

The floor loads was transferred to the selected frame depending on the weight of the floor slab and the end conditions. Accordingly the following result was obtained.

Panel 1, $G_K = 2.73 \text{ kN/m}^2$, $Q_K = 1.5 \text{ kN/m}^2$, size 4.17x4.17m, restrained along one side.

Panel 2, $G_K = 2.52 \text{ kN/m}^2$, $Q_K = 1.5 \text{ kN/m}^2$, size 4.17x4.17m, restrained along two sides.

Panel 3, $G_K = 2.73 \text{ kN/m}^2$, $Q_K = 1.5 \text{ kN/m}^2$, size 4.17x4.17m, restrained along one side.

Floor loads transferred to frame 2-2

from panel 1 = 3.56 kN/m

panel 2 = 2.55 kN/m

panel 3 = 4.52 kN/m

Floor loads transferred to frame c-c

from panel 1 = 0 kN/m
 panel 2 = 2.81 kN/m
 Panel 3 = 3.56 kN/m

Depth of the upper tie beam.

$$d = [(0.4 + (0.6 f_{yk}/400)) L_e / \beta_a]$$

$f_{yk} = 300 \text{ MPa}$, $\beta_a = 24$ (end span one end continuous)

L_e = Effective span $4.20 - (0.2/2) = 4.00 \text{ m}$.

$$d = [0.4 + 0.6 (300/400)] (4000/24) = 142 \text{ mm}$$

take $D = 300 \text{ mm}$ and $d = 300 - 25 = 275 \text{ mm}$

$b = 250 \text{ mm}$ (to go with the column size)

column size $250 \times 250 \text{ mm}$.

The loads from separate elements (columns, beams, walls) were calculated and transferred to the selected frames.

Loads on frame C-C (kN/m)

<u>Roof</u>		
	<u>Span1</u>	<u>Span 2</u>
Roofing	14.91	4.11
upper tie beam	<u>2.44</u>	<u>2.44</u>
Total	<u>17.35</u>	<u>6.55</u>
<u>1st floor</u>		
floor slab	2.81	3.56
wall	13.81	13.81
beam	0.83	0.83
edge girder	<u>0.68</u>	<u>0.68</u>
Total	<u>18.13</u>	<u>18.88</u>
<u>Ground floor</u>		
floor slab	0	0 (rests on the ground)
wall	13.81	13.81
beam	<u>2.44</u>	<u>2.44</u>
Total	<u>16.25</u>	<u>16.25</u>

Loads on frame 2-2

<u>Roof</u>		
	<u>Span1</u>	<u>Span 2</u>
Roofing	0	0 (Gable side)
wall (triangular)	0	2.00
upper tie beam	<u>2.44</u>	<u>2.44</u>
Total	<u>2.44</u>	<u>4.44</u>
<u>1st floor</u>		
floor slab	7.07	3.56
wall	9.2	7.15
beam	0.83	0.83
edge girds	<u>0.68</u>	<u>0.68</u>
Total	<u>17.78</u>	<u>12.22</u>
<u>Ground floor</u>		
floor slab	0	0
wall	0	0
beam	<u>2.44</u>	<u>2.44</u>
Total	<u>2.44</u>	<u>2.44</u>

The final load distribution on the frames is as shown in fig. 5.6

5.4.4. Frame Analysis of 25x25cm Columns

5.4.4.1 Analysis of vertical and lateral loads

Based on the Ethiopian standard code of practice of 1983

$$F_{tot} = C_s G_{eq} = \alpha \beta \gamma G_{eq}$$

$$G_{eq} = G_k + \psi Q_k$$

where: C_s = seismic base coefficient

G_{eq} = permanent equivalent load

G_k = the characteristic dead load

Q_k = the characteristic live load

ψ = live load incidence factor

ψ = 0.25 for private dwellings

The total dead and live loads of the building are summarized as follows:

$$\text{Roof} = \text{total load} = 172.26 \text{ kN}$$

by ratio from the total load on the truss Q_k is

$$Q_k = [1.6(0.45)/0.92] \times (172.26) = 134.81 \text{ kN}$$

$$GK = 172.26 - 134.81 = 37.45 \text{ kN}$$

$$\text{. load of roof beam} = 99.94 \text{ kN}$$

$$\text{. load of walls} = 45.86 \text{ kN}$$

$$\text{Total dead load (GK)} = 37.45 + 99.94 + 45.56 = 182.95 \text{ kN}$$

First floor

$$\text{D.L, . columns} = 43.88 \text{ kN}$$

$$\text{. floor slab} = 163.56 \text{ kN}$$

$$\text{. beam} = 33.38 \text{ kN}$$

$$\text{. Edge girder} = 147.63 \text{ kN}$$

$$\text{. Walling} = 267.09 \text{ kN}$$

$$\text{Total GK} = 655.51 \text{ kN}$$

$$\text{L.L, Total Qk} = 226.89 \text{ kN}$$

Ground floor

$$\text{D.L. . columns} = 43.88 \text{ kN}$$

$$\text{. floor slab} = 0.0 \text{ (rests on the ground)}$$

$$\text{. beams} = 77.03 \text{ kN}$$

$$\text{. Walling} = 267.09 \text{ kN}$$

$$\text{. stair and landing} = 35.6 \text{ kN}$$

$$\text{Total GK} = 423.63 \text{ kN}$$

$$Qk = 0 \text{ (rests on the ground)}$$

Total load of the building

	<u>GK (kN)</u>	<u>QK (kN)</u>
Roof	182.95	118.12
1st floor	655.51	226.89
Ground floor	<u>423.63</u>	<u>0</u>
Total	<u>1262.09</u>	<u>345.01</u>

$$G_{eq} = 1262.09 + 0.25 \times 345.01 = 1348.34 \text{ kN}$$

$$C_s = \alpha \beta \gamma \quad \alpha = \alpha_0 I \quad \alpha_0 = 0.05 \quad (\text{zone 2})$$

$$\alpha = 0.05 \times 1 = 0.05, \quad I = 1.0 \text{ (for occupancy)}$$

$$\beta = \beta_0 \leq 2.5 \quad \beta_0 = 1.2 \sqrt{T}$$

$$T = (0.09 h_n) / \sqrt{d} = (0.09 \times 9.3) / \sqrt{(8.65)} = 0.25$$

$$d = 8.65 \text{ m (least plan dimension of the building)}$$

$$h_n = \text{total height of the building}$$

$$\beta_0 = 1.2 / \sqrt{(0.25)} = 2.4$$

$$\beta = \beta_0 S = 2.4 \times 1.5 = 3.6 > 2.5 \text{ (so take } \beta = 2.5)$$

(the worst case taken for 'S')

$$\gamma = 0.4$$

$$C_s = 0.05 \times 2.5 \times 0.4 = 0.05$$

$$F_{\text{tot}} = C_s G_{\text{eq}} = 0.05 \times 1348.34 = 67.42 \text{ kN (total force in each direction)}$$

$$T = 0.21 < 0.7 \Rightarrow F_n = 0$$

In ordinary frame, satisfactory results may be obtained with the assumption of simple shear force distribution. This is because the influence of shear force distribution on the D-value is extremely small except when relative stiffness ratio, K , of beams to columns is especially small, for example, $K < 0.5$. So, the effect of torsion is negligible.

Thus, for the present work the load was distributed equally per frame.

$$\approx \text{load per frame } 67.42/3 = 22.76 \text{ kN.}$$

The distribution of total lateral forces over the height of the building in both directions is as follows:

$$F_x = [(F_{\text{tot}} - F_{\text{no}}) G_x h_x] / \sum(G_i h_i)$$

Roof

$$\begin{aligned} F_x &= [(22.76 - 0) (182.95 \times 8.3)] / [182.95 \times 8.3 + (655.51 \times 4.2) + (423.63 \times 1.50)] \\ &= 7.48 \text{ kN} \end{aligned}$$

1st floor

$$F_x = [(22.76 - 0) (655.51 \times 4.2)] / (4907.07) = 12.41 \text{ kN}$$

Ground floor

$$F_x = [(22.76 - 0) (423.63 \times 1.5)] / (4907.07) = 2.86 \text{ kN}$$

The lateral load distribution for both directions (frames) is as shown in figure-5.6.

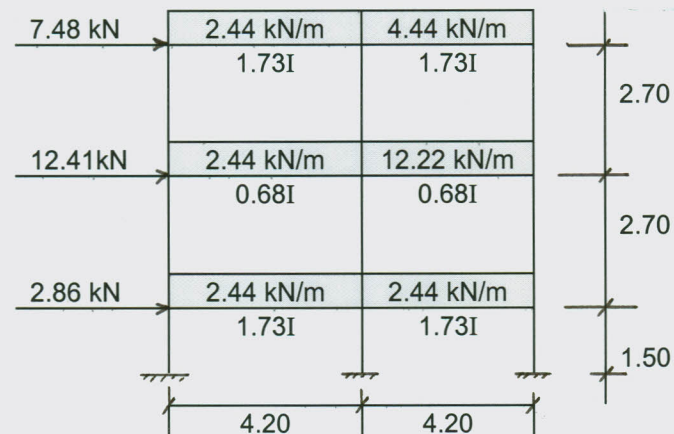
Moments of inertia (I)

- . Column 0.25x0.25m $I = (250 \times 250^3) / 12 = 0.325 \times 10^9 \text{ mm}^4$
- . beam 1 0.25x0.30m $I = 0.563 \times 10^9 \text{ mm}^4$
- . beam 2 0.25x0.22m $I = 0.222 \times 10^9 \text{ mm}^4$

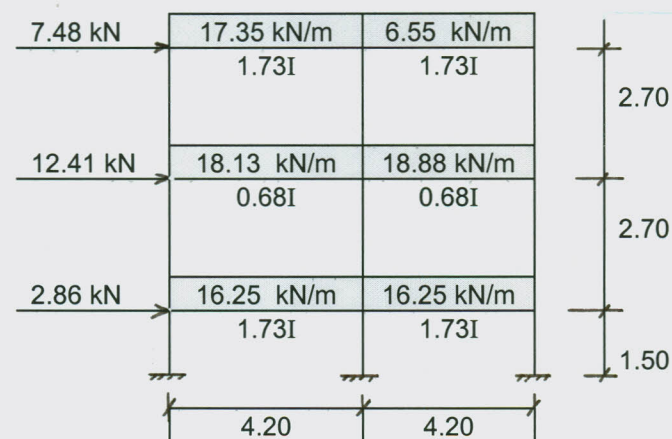
Relative moments of inertia.

- . Column = I
- . beam 1 = 1.73 I (Roof & Grade beams)
- . beam 2 = 0.68 I (First floor beam)

Frame analysis was carried out using SAP80 software. Finally the maximum shear forces and bending moments were obtained.



a) Frame 2 - 2



b) Frame C - C.

Fig. 5.6 vertical load distribution on the selected frames and the lateral loads.

5.4.4.2 Design of the columns (25cm)

The combined axial forces and bending moments were obtained from the calculations. The design of the column was carried out using the provisions of Ethiopian Code of Practice, ESCP2, 1983.

- Columns can be classified as unbraced.
- Slenderness ratio λ is given by $\lambda = L_e / i$

Where:

L_e = effective buckling length

i = radius of gyration.

λ , The slenderness ratio of concrete columns shall not exceed 140.

L_e , the effective buckling length is the lesser of the following.

$$1) \quad L_e = L (1.0 + 0.15 (\alpha_{c1} + \alpha_{c2}))$$

$$2) \quad L_e = L (2.0 + 0.03 (\alpha_{cmin}))$$

L = Clear height between end restraints.

$$= 270 - [15 + 11] = 244 \text{ cm (1st and ground floor columns)}$$

$$= 270 - [11 + 15] = 244 \text{ cm (1st and ground floor columns)}$$

$$= 150 - [15] = 135 \text{ cm (foundation column)}$$

Take columns 4,5, & 6, at junction 2-B.

The effective length L_e is given by.

1st floor column

$$L_e = 244 [1.0 + 0.15 (0.287 + 1.471)] = 308$$

$$L_e = 244 [2.0 + 0.03 (0.289)] = 490$$

Ground floor

$$L_e = 244 [1.0 + 0.15 (1.471 + 0.578)] = 319$$

$$L_e = 244 [2.0 + 0.03 (0.578)] = 492$$

foundation column

$$L_e = 150 [1.0 + 0.15 (0.578 + 0)] = 163$$

$$L_e = 150 [2.0 + 0.03 (0)] = 300$$

$$\lambda = L_e / i$$

$$i = \sqrt{I/A} = \sqrt{(250 \times 250^3) / 12 (250)^2} = 72.17$$

$$\begin{aligned}
 \text{1st floor } \lambda &= 308/72.17 = 4.27 \\
 \text{Ground floor } \lambda &= 319/72.17 = 4.42 \\
 \text{foundation } \lambda &= 163/72.17 = 2.26 \text{ all OK } < 140.
 \end{aligned}$$

Eccentricity

$$\begin{aligned}
 e_{\text{tot}} &= e_o + e_i + e_2 \\
 e_o &= M_u / N_u \\
 e_i &= L_e / 300 \geq 20 \text{ mm} \\
 e_2 &= 0.06h \left(\frac{L_e}{10h} \right)^2
 \end{aligned}$$

$$\begin{aligned}
 \text{1st floor: (column 6)} \\
 e_i &= L_e / 300 = 308 / 300 = 1.03 \text{ cm, take 20 mm} \\
 e_2 &= 0.06 (250) [308 / (10(250))]^2 = 0.23 \text{ mm}
 \end{aligned}$$

$$N_u = \text{axial load} = 54.4 + 14.6 = 69 \text{ kN}$$

$$M_u = M_{22} = 7.6 \text{ kNm} \quad M_{cc} = 8.01 \text{ kNm.}$$

$$e_{o22} = 7.6/69 = 0.110\text{m} \quad e_{occ} = 8.01/69 = 0.116\text{m in frame 2-2 direction}$$

$$e_{\text{tot}} = 0.11\text{m} + 0.020\text{m} + 0.00023\text{m} = 0.1302\text{m.}$$

$$M_u = e_{\text{tot}} \times N_u = 0.1302 \times 69 = 9 \text{ kN-m}$$

$$e_{\text{tot}} = e_{\text{tot}} \text{ in frame c-c direction}$$

$$e_{\text{tot}} = 0.116 + 0.020 + 0.0009\text{m} = 0.1362\text{m.}$$

$$M_u = 0.1362 \times 69 = 9.4 \text{ kN-m}$$

$$\begin{aligned}
 n_u &= N_u / f_{cd} b h \quad \text{and} \quad m_u = M_u / f_{cd} b h^2 \\
 f_{cd} &= 11.17, \quad b = h = 250 \text{ mm.}
 \end{aligned}$$

Ground floor (column 5)

$$N_u = 79.32 + 133.6 = 212.92 \text{ kN}$$

$$M_u = M_{cc} = 12.62 \text{ kN-m} \quad M_{22} = 12.6 \text{ kN-m}$$

$$e_i = 319/300 = 1.06\text{cm} = 10.6\text{mm take 20 mm.}$$

$$e_2 = 0.06 (250) [319/10(250)]^2 = 0.24 \text{ mm}$$

In c-c direction.

$$e_o = 12.6/212.9 = 0.059\text{m}$$

$$e_{\text{tot}} = 0.059 + 0.020 + 0.0002 = 0.0792\text{m.}$$

$$M_u = 0.0792 \times 212.92 = 16.84 \text{ kN-m.}$$

In frame 2-2 direction.

$$e_0 = 12.6/212.9 = 0.059 \text{ (the same in both directions)}$$

Foundation column (column 4)

$$N_u = 205.3 + 89.4 = 294.7 \text{ kN}$$

$$M_u = M_{22} = 10.5 \text{ kN} \cdot \text{m} \quad M_{cc} = 10.5 \text{ kN} \cdot \text{m}.$$

$$e_i = 163/300 = 0.54 \text{ cm} \Rightarrow \text{take } 20 \text{ mm}.$$

$$e_2 = 0.03 \text{ mm}$$

$$e_0 \text{ for both direction, } e_0 = M_u/N_u = 10.5/294.7 = 0.036 \text{ m}.$$

$$e_{\text{tot}} = 0.036 + 0.00003 + 0.020 = \underline{0.05603 \text{ m}}.$$

Take the maximum case to have uniform size of column.

For foundation column

$$N_u = 294.7 \text{ kN}$$

$$M_u = e_{\text{tot}} \times N_u = 0.05603 \times 294.7 = 16.5 \text{ kN} \cdot \text{m}.$$

$$\eta u = N_u / f_{cd} b h = 294.7 \times 10^3 / (11.17 \times 250 \times 250) = 0.42$$

$$\mu u = M_u / f_{cd} b h^2 = 16.5 \times 10^6 / 11.17 \times 250 \times 250^2 = 0.09$$

$$\Rightarrow \omega \approx 0.0 \text{ Use } A_{s \text{ min}}.$$

$$\ell = A_s / b h.$$

$$\text{use } d' = 45 \text{ mm} \quad d'/h = 45/250 = 0.18$$

$$f_{yd} = f_y k / \gamma = 300 / 1.15 = 260.9 \text{ N/mm}^2$$

Ground floor column

$$N_u = 212.92 \text{ kN}$$

$$M_u = 0.0792 \times 212.92 = 16.84 \text{ kN} \cdot \text{m}$$

$$\eta u = 212.92 \times 10^3 / (11.17 \times 250 \times 250) = 0.30$$

$$\mu u = 16.84 \times 10^6 / (11.17 \times 250 \times 250^2) = 0.09$$

$$\omega \approx 0.0 \text{ Use } A_{s \text{ min}}.$$

In both cases A_s minimum is sufficient.

$$\ell_{\text{min}} = 0.008, \quad A_s = \ell b h$$

$$A_s = 0.008 \times 250 \times 250 = 500 \text{ mm}^2$$

use 4 $\varnothing 14$

For lateral reinforcement use $\varnothing 6$ with center to center spacing of 12d.

$$12 \times \text{min. diam.} = 12 \times 14 = 168$$

So, use $\varnothing 6$ c/c 165 mm.

5.4.5 Frame Analysis of 30x30cm columns

5.4.5.1 Analysis for vertical and lateral loads

The use of 30x30cm column induces variations in the vertical load. The variations are the dead loads of the columns, the roof and ground floor beams as well as the moments of inertia of the same elements. Making the necessary adjustments the shear forces and moments were to be calculated.

- For vertical loading the same loading patterns exist except for the changes in beam and column dead loads.
- For the lateral loads consideration;
 - 1st floor, column DL = $1.3 \times 8 \times (0.30 \times 0.30) \times 2.70 \times 25 = 63.18 \text{ kN}$
 - Ground floor, column DL = same = 6.18 kN
 - beam (roof and grade) 30x30cm = $1.3 \times 0.3 \times 0.3 \times 25 = 2.93 \text{ kN/m}$.

Total load of the building

Roof	<u>GK (kN)</u>	<u>QK (kN)</u>
	219.93	118.12
1st floor	674.81	226.89
Ground floor	<u>466.52</u>	<u>0</u>
Total	1361.26	345.01

$$G_{eq} = 1361.26 \times 0.25 \times 345.01 = 1447.51 \text{ kN}$$

$$F_{tot} = C_s G_{eq} + 0.05 \times 1447.51 = 72.38 \text{ kN (total force on each direction).}$$

- load per frame = $72.38/3 = 24.13 \text{ kN}$
- The lateral forces per storey level are.

$$F_{\text{roof}} = [(24.13 - 0) 219.93 \times 8.3] / [(219.93 \times 8.3) + (674.81 \times 4.2) + (466.52 \times 1.50)]$$

$$= 44047.36 / 5359.40 = 8.22 \text{ kN}$$

$$F_{\text{1st floor}} = [(24.13 - 0) 674.81 \times 4.2] / 5359.40 = \underline{\underline{12.76 \text{ kN}}}$$

$$F_{\text{G. floor}} = (24.13 - 0) 466.52 \times 1.50 / 5359.40 = \underline{\underline{3.15 \text{ kN}}}$$

Moments of inertia

$$\begin{aligned}
 I_{\text{column}} &= 300 \times 300^3 / 12 = 6.75 \times 10^8 \text{ mm}^4 \\
 I_{\text{beam (top \& bottom)}} &= 300 \times 300^3 / 12 = 6.75 \times 10^8 \text{ mm}^4 \\
 I_{\text{beam 1st floor}} &= 300 \times 220^3 / 12 = 2.662 \times 10^8 \text{ mm}^4
 \end{aligned}$$

Relative moments

$$\begin{aligned}
 I_{\text{column}} &= I \\
 I_{\text{beam (Top \& bottom)}} &= I \\
 I_{\text{beam (1st floor)}} &= 0.3944 I
 \end{aligned}$$

The lateral and vertical load distribution on frames is as shown in figure-5.7.

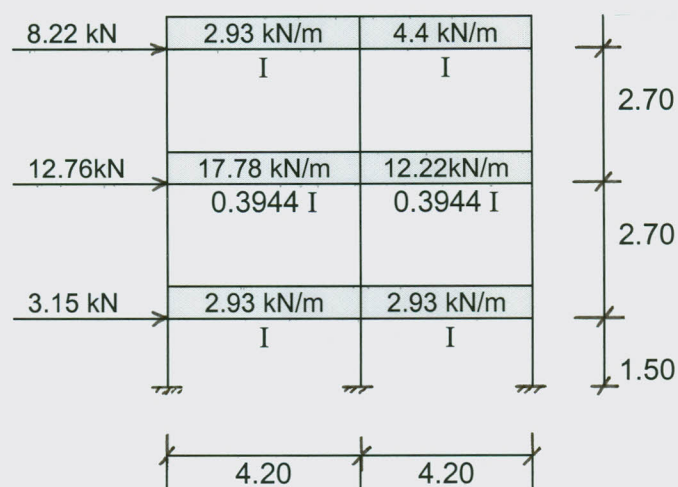
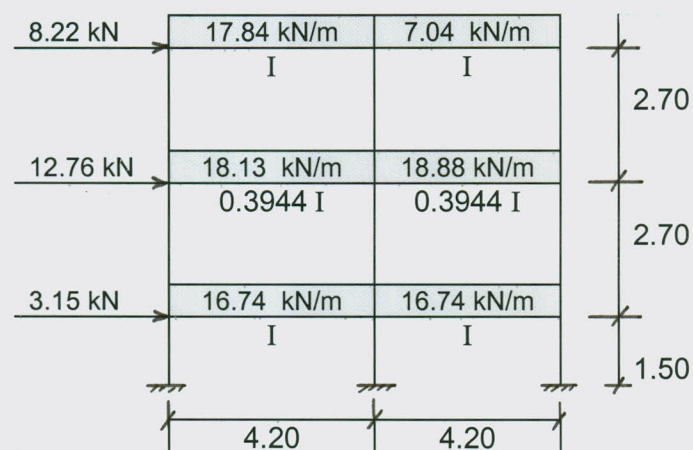
**Frame 2 - 2****Frame C - C.**

Figure 5.7 Vertical and horizontal load distribution on the selected frames for 30x30cm columns

5.4.5.2 Design of 30x30cm columns

The basic calculations for 25x25 cm column holds true for 30x30 cm column except for minor changes.

Slenderness ratio.

$$\lambda = L_e/i \quad \text{where } i = \sqrt{I/A} = \sqrt{300 \times 300^3 / (12 \times (300)^2)} = 86.6$$

Take the same column, (column 6, 5 and 4)

1st floor	$\lambda = 308/86.6$	$= 3.56$
Ground floor	$\lambda = 319/86.6$	$= 3.68$
Foundation	$\lambda = 163/86.6$	$= 1.88$ all OK < 140.

Eccentricity

$$e_{tot} = e_o + e_i + e_2$$

1st floor (column 6)

$$e_i = L_e/300 = 308/300 = 1.03 \text{ cm} \Rightarrow \text{so, take 20 mm.}$$

$$e_o = 0.06 (300) [308 / (10 \times 300)]^2 = 0.19 \text{ mm}$$

$$\text{Axial load, } N_u = 55.38 + 15.50 = 70.88 \text{ kN}$$

$$\text{Moment, } M_u = M_{22} = 9.81 \text{ kN-m, } M_{cc} = 10.04 \text{ kN-m.}$$

$$e_o = M_u/N_u = 10.04/70.88 = 0.1416 \text{ m}$$

$$e_{tot} = 0.1416 + 0.020 + 0.0002 \text{ m} = 0.1618 \text{ m}$$

Ground floor (column 5)

$$N_u = 133.74 + 79.39 = 213.13 \text{ kN}$$

$$M_u = M_{cc} = -13.97 \text{ kN-m} \quad M_{22} = -13.97 \text{ kN-m.}$$

$$e_i = 319/300 = 1.06 \text{ cm} \Rightarrow \text{so, take 20 mm.}$$

$$e_2 = 0.06 (300) [319 / (10 \times 300)]^2 = 0.20 \text{ mm}$$

$$e_o = 13.97/213.13 = 0.066 \text{ m.}$$

$$e_{tot} = 0.066 + 0.020 + 0.0002 = 0.0862 \text{ m.}$$

Foundation column (column 4)

$$N_u = 206.32 + 91.63 = 297.95 \text{ kN}$$

$$M_u, M_{22} = M_{cc} = 12.92 \text{ kN-m.}$$

$$e_i = 163/300 = 0.54 \text{ cm} \Rightarrow \text{take 20 mm.}$$

$$e_2 = 0.06 (300) [163 / (10 \times 300)]^2 = 0.05 \text{ mm} \approx 0$$

$$e_o = 12.92/297.95 = 0.043 \text{ m.}$$

$$e_{tot} = 0.043 + 0.020 + 0.00005 = 0.063 \text{ m.}$$

The reinforcement required, taking the maximum case of loading is,

1st floor

$$N_u = 70.88 \text{ kN}$$

$$M_u = e_{\text{tot}} \times N_u = 0.1618 \times 70.88 = 11.50 \text{ kN-m.}$$

$$n_u = 70.88 \times 10^3 / 11.17 \times 300 \times 300 = 0.07$$

$$m_u = 11.50 \times 10^6 / 11.17 \times 300 \times 300^2 = 0.04$$

$$\omega = 0.01 \quad \text{use } A_s \text{ min}$$

Ground Floor

$$N_u = 213.13 \text{ kN}$$

$$M_u = 0.0862 \times 213.13 = 18.4 \text{ kN-m}$$

$$n_u = 213.13 \times 10^3 / 11.17 \times 300 \times 300 = 0.21$$

$$m_u = 18.4 \times 10^6 / 11.17 \times 300 \times 300^2 = 0.06$$

$$\omega = 0.01 \quad \text{use } A_s \text{ min}$$

Foundation floor

$$N_u = 297.95 \text{ kN}$$

$$M_u = 0.063 \times 297.95 = 18.9 \text{ kN-m.}$$

$$n_u = 297.95 \times 10^3 / 11.17 \times 300 \times 300 = 0.30$$

$$m_u = 18.9 \times 10^6 / 11.17 \times 300 \times 300^2 = 0.06$$

$$\omega = 0.01 \quad \text{use } A_s \text{ min}$$

$$\ell_{\text{min}} = 0.008$$

$$A_s = \ell_{\text{min}} b h = 0.008 \times 300 \times 300 = 720 \text{ mm}^2$$

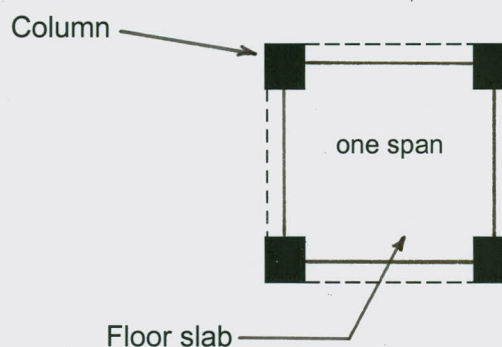
use 4 $\varnothing 16$, 4 $\varnothing 16$ is sufficient throughout.

For lateral reinforcement, $12d = 12 \times 16 = 192 \text{ mm}$

use $\varnothing 6$ c/c 190 mm

Joints

To test the strength of the joints the following calculation was carried out.



- Take a load of dead load (finishing + partition) = 5 kpa
- live load = 1.5kpa
- total** = **6.5kpa**

$$\text{Total floor area} = 4.20 \times 4.20 = 17.64\text{m}^2$$

Total weight of the floor under full loading is equal to 114.66 kN (6.5x17.64). This load is transferred to the columns via eight contact surfaces, so each joint takes a load of 14.33kN (114.66/8). The floor slabs are connected to the columns by prestressing and there is a force of 300 kN at each contact surface. Taking a coefficient of friction of $\mu=0.5$; the frictional force at each joint is,

$$F = P \times \mu = 300 \times 0.5 = 150\text{kN}$$

So, taking only the frictional force into account, the shear safety factor is equal to $\eta=10.5$ (150/14.33) which shows sufficient margin of safety.

5.5 Concluding Remarks

Based on the statical analysis of the model G+1 building the following conclusion can be forwarded.

- Low-rise G + 1 building can be constructed using 25 x 25 cm column frames with 4 Ø 14 longitudinal reinforcement bars.
- The existing 30 x 30 cm precast column with 4 Ø 19 longitudinal reinforcement is not economical for low - rise buildings. Statical analysis shows that 4Ø16 can suffice even if 30 x 30 cm column is to be used, yet with extra strength.
- The design of reinforcements including lateral reinforcement of the existing precast column can be classified as a conservative design.
- Incorporating minor architectural changes, a 25 x 25 cm precast column can be used for low - rise buildings.
- The existing precast elements of PBPPE should be given standards acknowledged by the responsible Authority for design standards, the Ministry of Works and Urban Development.
- The precast elements available can be used for different building layouts to accommodate the diverse needs of the public.

The following standard modules are proposed for low rise building.

a) 25 x 25 cm column

- Length 2.70m center to center for one storey or it can be produced for two storey in one run.

b) 4.20 x 4.20 m normal floor slab

- The slab can be modified on the four edges to accommodate the 25x25cm column.
- The reinforcements too are to be varied slightly in line with the modification.
- Floor slab with a hole of 2.60x2.00m for staircase can be produced with ribs at the edges of the hole that serve as a beam where the stairflight rests.

c) Edge girder of 17 cm.

- The length of the chosen 17 cm wide edge girder is adjusted in line with the changes in the floor slab.

The precast elements proposed has to be seen with the existing precast modules of the enterprise and specific designs has to be performed. The new elements need further modification of non structural parts that have to be used during erection. These include holes for supporting the floor slabs before prestressing, erection apparatus and small tools should be modified to suit to the new modules.

In addition further investigation has to be performed in order to promote the use of prefabricated elements.

6.0 Precast Concrete Special applications

The many benefits of precast/prestressed concrete make it suitable for many other types of structures. The high degree of design flexibility make it ideal for a wide variety of special applications. Corrosion resistance, fire resistance, durability and fast installation of precast concrete have been the good advantages of it. With repetition and standardization, precast concrete components can economically be used to have plant manufactured products with an elimination of expensive and risky field procedures. In all precast concrete construction, the important prerequisite is to have the largest possible number of identical components.

Precast/prestressed concrete products are designed in accordance with the latest engineering standards and produced in plants with certificates that assure their quality. Accordingly various precast concrete sections are produced depending on the specific needs. The I-beam, box beam and bulb tee are used in bridge construction. The inverted tee, and rectangular beam are used for structural framing to support deck members. Square or rectangular columns are an integral part of the column-beam-deck framing that makes rapid, all-weather erection possible. Piles are manufactured in a variety of shapes including round, square, hexagonal and octagonal, as well as rectangular sheet piles. Channel slabs are used to support heavy floor loads in short and medium spans.

The developments in products, materials and techniques have made precast/prestressed concrete competitive in a variety of residential, commercial, transportation and many other types of structures. This has formed the basis for configuring a wide variety of framing systems for buildings, bridges and other structures. The following provides an overview of its applications to different types of structures (PCI, 1992).

6.1 Parking Structures

Precast/prestressed concrete has turned to be the solution for commercial, municipal and institutional parking needs. Parking structures are unique and similar to other buildings but in some ways, they may be compared to bridges with multiple decks. They are subjected to moving loads from automobile traffic. At the same time parking structures are exposed to weather in much the same way as bridges. Furthermore, they are usually not enclosed and thus the entire structure is subjected to ambient weather conditions. Their exposure to harsh weather especially in coastal locations requires consideration to ensure long-time performance of the structure.

Precast concrete, produced in plants in controlled conditions, assures the parking structure to be of high quality concrete and workmanship that provides long term durability. The low water-cement ratio concrete that precast concrete manufacturers use and the accelerated curing system have been proven to increase resistance to corrosion due to chlorides (PCI).

These inherent durability along with the low-cost, rapid erection in all weather conditions, unlimited architectural expression and long clear spans make precast concrete the natural choice for parking structures. Long term accumulated experience and surveys of the existing structure has lead to significant improvements in planning, design, construction and maintenance of parking structures.

6.2. Warehouses and Industrial buildings

The long span and small depths of precast/prestressed concrete and its ability to carry heavy loads makes it particularly suitable for warehouses and industrial buildings. Standard components such as walls, insulated or non-

insulated, are very economical for warehouse and light manufacturing applications. Total precast systems with precast/prestressed roof diaphragms and shear walls can provide a complete structural package.

In heavy industrial projects, precast components capable of carrying the typical heavy floor loads are used to construct versatile, corrosion-resistant structural systems. Precast elements can be designed to accommodate a variety of mechanical systems and to support bridge cranes for industrial uses. High quality precast concrete provides protection against fire, dampness and a variety of chemical substances. The smooth surfaces achievable in precast concrete make it ideal for food processing, wet operations, as well as many other types of manufacturing operations. Long spans to about 45m with bridge-type girders and clear spans of 12-25m hollow core slabs and double tee precast concrete can be effectively used in industrial buildings.

6.3 Justice facilities

Justice facilities encompass many types of building occupancies which include jails, prisons, police stations, courthouses, etc. Precast/prestressed concrete has proven to be the favored material for justice facilities because it has many inherent benefits which are important to these building types. The use of precast/prestressed ensures among other things, fire resistance, durability, speed of erection and flexibility for aesthetics, etc. Precast/prestressed concrete is ideal for building in the desired level of physical security as well as an accommodation of security hardware and communication systems. The thickness and reinforcement of precast wall and slab systems, designed for gravity and lateral loads and volume changes, are generally sufficient even for maximum security requirements. Also, the modular nature of precast/prestressed concrete products facilitates pre-installation of

necessary security and communication hardware in the plant, greatly simplifying field installation work as well as saving valuable time.

For justice facilities the use of precast concrete box modules in a one-cell or two-cell format has greatly reduced field labor, erection time, punch list problems and ultimately - risk-. These units can be quickly stacked and can be substantially complete requiring little finishing work. The serious shortage of justice facilities, savings in total project time is often a critical consideration in selection of a structural material and system for these projects.

6.4 Stadiums / arenas

Large stadiums and arenas are impressive structures because of their aesthetic view. Often these projects are built on tight schedules to accommodate some important sporting event. Precast/prestressed concrete has been the overwhelming choice for many of these projects. The technique of post-tensioning precast segments together has allowed this versatile material to form complex cantilever arm and ring beam construction which supports the roofs of these structures. Post-tensioning is also commonly employed to minimize the depth of precast concrete cantilevered raker beams which carry the seating and provide unhindered viewing of the playing surface. Mass produced seating units have been manufactured in a variety of configurations and spans to provide quick installation and long lasting service. The ability to eliminate costly field formwork makes precast/prestressed concrete the best choice for many components of stadium construction, especially seating which can be standardized to take advantage of repeated form utilization. Components that would require tall scaffolding towers can be simplified by precasting in a plant and delivering and lifting them into place. Various sections such as pedestrian ramps, mezzanine floors, toilet, and dressing room areas can all be framed and constructed using precast/prestressed concrete elements.

6.5 Bridges

Precast/prestressed concrete is now the dominant structural material for short-to-medium span bridges. With its inherent durability, low maintenance and assured quality, precast/prestressed concrete is a natural product for bridge construction. The ability to quickly erect precast concrete components in all types of weather with little disruption of traffic adds to the economy of the job. Box sections and double tee sections has proved to be economical for short spans. The most commonly used section for short-to-medium spans is the I-girder. I-girders and bulb tees with spans of 45- 50m and spliced girders of upto 90m are common in bridge construction. Even longer spans (90 to 120m) can be achieved using precast box girder segments which are then post-tensioned in the field. By the use of cable stays, the spanning capability of precast/prestressed concrete has been increased to over 300m.

Another growing application of precast/prestressed concrete in bridge construction includes the use of precast deck panels. The panels reduce field placement of reinforcing steel and concrete resulting in considerable savings. They form composite with the cast-in-situ concrete for live loads.

The use of precast/prestressed for bridge structures is at an infancy level in Ethiopia. The Abay Bridge incorporates new technological achievements in bridge construction of Ethiopia. It constitutes the only precast/prestressed bridge built to date in the country (see figure 6.1). The construction of the bridge was completed in 1993. The Abay Bridge is located at 190.4 km from Nekemte on the road to Burie. The total length of the bridge, measured between abutments along the road center line is 238.13 meters. The bridge has an access viaduct made of two independent reinforced concrete bridge decks with a span of 12m at both sides and a prestressed concrete bridge with two spans of 52.6m each and 85.0m (ERA,1991).

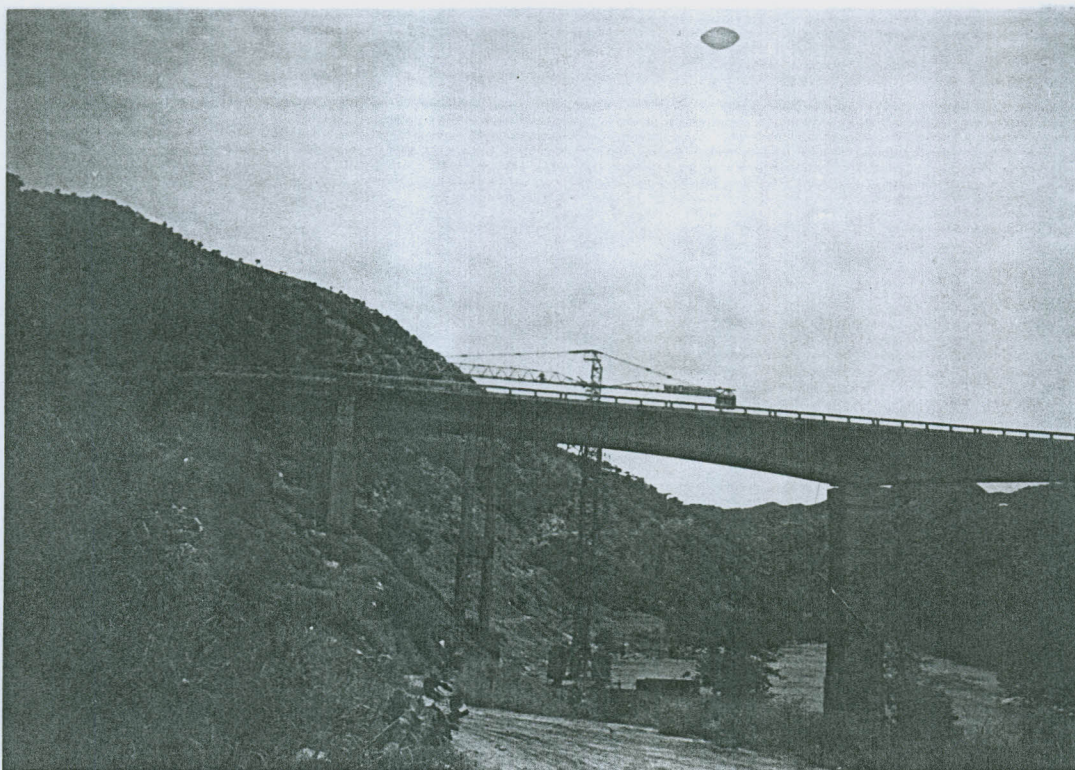


Figure 6.1 Abay River Precast Bridge



Fig. 6.2 Kechin Abeba precast concrete bridge

The prestressed concrete deck is made by cast in situ construction built in cantilever segments. The cross section is a box girder with vertical webs 40cm. The depth of the box girder varies parabolically from 2.5m upto 5.0m. The bridge is prestressed longitudinally by cables of 12 strands. The bridge is supported by reinforced concrete piers with hollow cores. The piers are of the same size and their height is 37.4m from top of pier cap to foundation level.

In a similar way precast concrete was used recently for Kechin Abeba bridge construction with a span of 114m on Dawnt-Lalibela rural road by Berta Construction plc. in 1997 (see figure 6.2). The use of the Y-shaped precast structural elements on the project has eliminated the huge use of wooden formwork hence saving time and money (Getachew, 1997).

6.6 Poles

Precast concrete poles are durable economical and provide low maintenance expenses. Power transmission poles support overhead power lines. They have to resist large horizontal forces functioning substantially as vertical cantilever, fixed at the base. The loading conditions determine the shape and more particularly the cross section of such poles. The cross-section of such poles should be symmetrical about two axes and should increase in the size towards the base of the pole to take account of the increase in bending moment. The frequently used cross sections are I-sections, box sections and hollow circular sections. Precast/prestressed power transmission poles are advantageous because prestressing prevents cracking of the structures and consequently the corrosion of the steel.

Various types of poles are manufactured in different countries, with different cross sections. The I-section poles are usually with circular apertures in the webs to reduce the weight. In most of the causes, the same molds can

be used for producing various types of poles, provided that the degree of taper is the same for all of them.

Supports for use at substations can be designed on the same principles as poles for overhead power lines. These precast supports need to have approximately equal moments of inertia in both directions.

6.7 Other applications

There are numerous applications of precast/prestressed concrete elements in addition to what have mentioned above.

- Precast arched culverts
 - allows quick erection
 - no or little site disruption
 - no field formwork
- Precast rail road ties
 - has proven to be a viable alternative to timber
 - highly repetitive components i.e. economical
 - durable
- Precast concrete sound barriers
 - protects residential neighborhood from highway noise
- Precast storage tanks
 - durable
 - resistance to ambient weather conditions
- Precast piles
 - eliminate an expensive over water formwork
 - easily resist the harsh marine environment
- Precast retaining walls
- Road side curbs
 - economical and durable
 - an alternative for stone curbs

7.0 Conclusions and Recommendations

7.1 Findings and conclusions

To investigate the use and development trends of precast concrete in Ethiopia, a review of the existing technical documents and a field survey for primary data was carried out. Based on the findings conclusions and recommendations are forwarded in order to promote the precast technology. The main conclusions of the research are the following.

- The Ethiopian construction industry is at the stage of infancy with significantly low level of technological background especially in precast concrete.
- Most professionals involved in the building industry generally prefer to use the conventional building methods with little efforts to incorporate new techniques in the building industry such as precasting.
- There is limited knowledge and experiences in precasting and as a result the attitudes towards its use is also limited.
- It is felt by some professionals, that precast concrete do have some inconveniences for the installation of electrical and sanitary fittings. But this do not have foundation because such conduits could be incorporated at the production stage if adequate working drawing are prepared at the design phase.
- Precast concrete construction techniques requires precise design works and perfection during production and erection that some professionals engaged in the construction industry do not dare to take such responsibility.
- The reinforcements of precast structural elements are arranged conservatively that the number and types of steel used, the different

diameters of steel in use and the arrangement itself requires excessive precaution that may result in time consumption.

- The available precast structural elements as well as the IMS system are not made well known to design offices in the country through publications, commercial advertisement in order to promote their use in the industry.
- All technical documents, published articles and books except the technical catalogue, are found in different sections of the enterprise as well as in different organizations. As a result, the existing technical documents, production and design guidelines are not easily accessible,
- Great efforts has to be done to promote the precast technology through dissemination of information preparing design and erection guidelines, simplified manuals and brochures,
- There is no adequate exterior quality control methods in a technology that requires high precision in production and erection.
- Adequate efforts were not carried out to show the merits and demerits of precasting emphasizing the effectiveness and efficiency of the technology as compared to other conventional construction methods. As a result of the study, it is believed, much has to be done in the future in marketing, and dissemination of information to promote the IMS precast/prestressed technology in Ethiopia.
- Structurally as well as technologically the IMS precast/prestressed system constitutes one of the high quality products of construction which was witnessed in a number of countries over the last 40 years.

7.2 Recommendations

The IMS precast structural system was found to be structurally sound, stable and flexible system, if sufficient alternative design solutions are reviewed even with the existing modules and sizes. The missing modular sizes can be incorporated through appropriate formwork and structural designs at the existing premise or such modular sizes could be imported from the IMS Institute. But, before taking such measures, comprehensive study incorporating the merits and demerits of the existing sizes, the cost incurred due to the introduction of new sizes and the demand for the new modules, should be carried out in order to evaluate the economic feasibility.

However, for efficient design solutions, the existing modules could be used for various alternatives with slight modification and with an incorporation of cast-in-situ concrete construction methods. This could be realized if the designers are aware of the system for its consideration in urban planning and detailed architectural designs.

To promote the use and development of precast concrete certain modules can be incorporated to the existing stock with slight modifications based on specific urban development plans and public needs as presented in chapter 5 of this work. Furthermore, the following recommendations are forwarded in order to enhance its development. The recommendations suggested for the development of precast concrete technology are :

- The construction industry should be given adequate support by the Government to promote the industry in general and precast concrete technology in particular.
- The experience of the developed nations shows that precasting paves the way to industrialized concrete technology. Thus to improve the technology, to establish standards of quality control and to encourage the transfer of technology, precast concrete associations need to be established. Such

institution issues certificates of quality and assures manufacturing plant's audited capacity to produce quality products.

- The enterprise in charge of the production and erection of the IMS system should collect all technical documents pertaining to the technology from different organization and make available in an organized section or library with sufficient copies to its own technical staff as well as for designers.
- Great effort should be done to disseminate technical information through simplified brochures, manuals, instructions and design guidelines and advertisements to raise public awareness of the technology.
- Using the initial works and the existing documents as a starting point, further research need to be conducted to improve the prevailing production and management system. For realistic solution, this should involve designers, precast concrete producers, and the end users. Such studies shall provide different design solutions and alternatives to be used by real state developers and consequently could enhance the development and use of precast technology.
- The available IMS modules should be incorporated to the National Design Codes after a thorough evaluation, if necessary; and the details be made available for utilization by design offices as per requirement. This includes the, demonstration of its safety, simplicity in erection and economical benefits.
- The long-term strategy of the enterprise should focus on the promotion of the technology by popularizing the IMS system and emphasizing the cost effectiveness, speed of construction and the simplicity of the system. Competing on normal construction bids especially in conventional construction methods can help a little if not none to develop the technology. It may help to make the enterprise profitable and sustainable, but such trends could not ensure the progress in precasting techniques. So, the Government through the cooperation of concerned technical institutions could have a role in the promotion of the technology.

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Annex

Two Dimensional Frame C-C (Static Analysis)/25cm/ /FCC/

SYSTEM

P=1 N=12 L=2 :No of joints and load conditions

JOINTS

1 Y= -4.20 Z= 0.0 X=0.0 :Left foundation joint
 4 Y= -4.20 Z= 1.5
 10 Y= -4.20 Z= 6.9 G=4,10,3 :Top left joint
 2 Y= 0.0 Z= 0.0
 5 Y= 0.0 Z= 1.5
 11 Y= 0.0 Z= 6.9 G= 5,11,3
 3 Y= 4.20 Z= 0.0 : Right foundation joint
 6 Y= 4.20 Z= 1.5
 12 Y= 4.20 Z= 6.9 G= 6,12,3 :Top Right joint

RESTRAINTS

1,12 R= 1,0,0,0,1,1 : All joints in Y-Z plane
 1,3 R= 1,1,1,1,1,1, : Fix foundation joints

CONSTRAINTS

5,6,1 C= 0,4 : Set axial deformation in beams to zero
 8,9,1 C= 0,7
 11,12,1 C= 0,10

FRAME

NM= 3 NL=5 P=1.0

C Member section properties

1 D= 0.25, 0.0 B= 0.25, 0.0 E=31e6
 2 D= 0.30, 0.0 B= 0.25, 0.0 E=26e6
 3 D= 0.22, 0.0 B= 0.25, 0.0 E=26e6

C Span loading Patterns

1 WL=0,-17.35
 2 WL=0,-6.55
 3 WL=0,-18.13
 4 WL=0,-18.88
 5 WL=0,-16.25

C Frame member location

C Columns

1,1,4 M=1 LP=3
 2,4,7 G= 1,1,3,3 M=1
 4,2,5 M=1
 5,5,8 G=1,1,3,3 M=1
 7,3,6 M=1
 8,6,9 G=1,1,3,3 M=1

C Beams

10,4,5 M=2 NSL=5
 11,7,8 M=3 NSL=3
 12,10,11 M=2 NSL=1
 13,5,6 M=2 NSL=5
 14,8,9 M=3 NSL=4
 15,11,12 M=2 NSL=2

LOADS

10 F=0,7.48 L=2
 7 F=0,12.41
 4 F=0,2.86

PRESTRESS

11 D= 0.065, 0.065, 0.065 T=300
 14 D= 0.065, 0.065, 0.065 T=300

C END

TWO DIMENSIONAL FRAME C-C (STATIC ANALYSIS)/25CM/
SAP80 V85.03

/FCC.F3F/

***** FRAME MEMBER FORCES *****

MEMBERS WITH NUMBERS BETWEEN 1 & 32000

MEM #	LOAD #	AXIAL FORCE	DIST I	1-2 PLANE SHEAR	1-2 PLANE MOMENT	1-3 PLANE SHEAR	1-3 PLANE MOMENT	AXIAL TORQUE
1		-104.10						
		.0	-10.16	4.84				
		1.5	-10.16	-10.40				
2		9.65						
		.0	6.19	-8.32				
		1.5	6.19	.97				
2		-71.71						
		.0	-5.92	8.33				
		2.7	-5.92	-7.65				
2		5.14						
		.0	5.82	-9.09				
		2.7	5.82	6.62				
3		-34.45						
		.0	-9.81	10.59				
		2.7	-9.81	-15.89				
2		2.01						
		.0	1.78	-.16				
		2.7	1.78	4.66				
4		-205.25						
		.0	.61	-.31				
		1.5	.61	.60				
2		.00						
		.0	10.37	-10.32				
		1.5	10.37	5.24				
5		-133.51						
		.0	-1.21	.91				
		2.7	-1.21	-2.37				
2		.00						
		.0	8.26	-12.52				
		2.7	8.26	9.78				
6		-54.54						
		.0	4.02	-2.79				
		2.7	4.02	8.07				
2		.00						
		.0	3.91	-3.04				
		2.7	3.91	7.52				
7		-82.98						
		.0	9.55	-4.59				
		1.5	9.55	9.73				
2		-9.65						
		.0	6.19	-8.32				
		1.5	6.19	.97				

8 -----				
1	-50.61			
	.0	7.13	-9.21	
	2.7	7.13	10.06	
2	-5.14			
	.0	5.82	-9.09	
	2.7	5.82	6.62	
9 -----				
1	-11.39			
	.0	5.78	-9.37	
	2.7	5.78	6.25	
2	-2.01			
	.0	1.78	-.16	
	2.7	1.78	4.66	
10 -----				
1	.00			
	.0	32.39	-18.73	
	2.0	.00	13.55	
	4.2	-35.86	-26.02	
2	.00			
	.0	-4.51	10.05	
	4.2	-4.51	-8.88	
11 -----				
1	.00			
	.0	.12	1.26	
	.3	.00	1.27	
	4.2	-1.74	-2.16	
2	.00			
	.0	-3.14	6.77	
	4.2	-3.14	-6.41	
12 -----				
1	.00			
	.0	34.45	-15.89	
	2.0	.00	18.31	
	4.2	-38.42	-24.24	
2	.00			
	.0	-2.01	4.66	
	4.2	-2.01	-3.76	
13 -----				
1	.00			
	.0	35.88	-26.32	
	2.2	.00	13.30	
	4.2	-32.37	-18.94	
2	.00			
	.0	-4.51	8.88	
	4.2	-4.51	-10.05	
14 -----				
1	.00			
	.0	2.94	-1.74	
	2.5	.00	1.88	
	4.2	-2.07	.07	
2	.00			
	.0	-3.14	6.41	
	4.2	-3.14	-6.77	
15 -----				
1	.00			
	.0	16.12	-16.17	
	2.5	.00	3.66	
	4.2	-11.39	-6.25	
2	.00			
	.0	-2.01	3.76	
	4.2	-2.01	-4.66	

Two Dimensional Frame 2-2 (Static Analyze)/25cm/ /F22/

SYSTEM

P=1 N=12 L=2 :No of joints and load conditions

JOINTS

1 Y= -4.20 Z= 0.0 X=0.0 :Left foundation joint
 4 Y= -4.20 Z= 1.5
 10 Y= -4.20 Z= 6.9 G=4,10,3 :Top left joint
 2 Y= 0.0 Z= 0.0
 5 Y= 0.0 Z= 1.5
 11 Y= 0.0 Z= 6.9 G= 5,11,3
 3 Y= 4.20 Z= 0.0 : Right foundation joint
 6 Y= 4.20 Z= 1.5
 12 Y= 4.20 Z= 6.9 G= 6,12,3 :Top Right joint

RESTRAINTS

1,12 R= 1,0,0,0,1,1 : All joints in Y-Z plane
 1,3 R= 1,1,1,1,1,1, : Fix foundation joints

CONSTRAINTS

5,6,1 C= 0,4 : Set axial deformation in beams to zero
 8,9,1 C= 0,7
 11,12,1 C= 0,10

FRAME

NM= 3 NL=4 P=1.0

C Member section properties

1 D= 0.25, 0.0 B= 0.25, 0.0 E=31e6
 2 D= 0.30, 0.0 B= 0.25, 0.0 E=26e6
 3 D= 0.22, 0.0 B= 0.25, 0.0 E=26e6

C Span loading Patterns

1 WL=0,- 2.44
 2 WL=0,-17.78
 3 WL=0,-4.4
 4 WL=0,-12.22

C Frame member location

C Columns

1,1,4 M=1 LP=3
 2,4,7 G= 1,1,3,3 M=1
 4,2,5 M=1
 5,5,8 G=1,1,3,3 M=1
 7,3,6 M=1
 8,6,9 G=1,1,3,3 M=1

C Beams

10,4,5 M=2 NSL=1
 11,7,8 M=3 NSL=2
 12,10,11 M=2 NSL=1
 13,5,6 M=2 NSL=1
 14,8,9 M=3 NSL=4
 15,11,12 M=2 NSL=3

LOADS

10 F=0,7.48 L=2
 7 F=0,12.41
 4 F=0,2.86

PRESTRESS

11 D= 0.04, 0.04, 0.04 T=300
 14 D= 0.04, 0.04, 0.04 T=300

C END

TWO DIMENSIONAL FRAME 2-2 (STATIC ANALYSIS)/25CM/ /F22.F3F/
SAP80 V85.03

***** FRAME MEMBER FORCES *****

MEMBERS WITH NUMBERS BETWEEN 1 & 32000

MEM	LOAD	AXIAL	DIST	1-2 PLANE	1-3 PLANE	AXIAL		
#	#	FORCE	I	SHEAR	MOMENT	SHEAR	MOMENT	TORQUE
1 -----								
1		-46.67						
		.0	.44	-.18				
		1.5	.44	.48				
2		9.65						
		.0	6.19	-8.32				
		1.5	6.19	.97				
2 -----								
1		-41.53						
		.0	-5.15	4.30				
		2.7	-5.15	-9.60				
2		5.14						
		.0	5.82	-9.09				
		2.7	5.82	6.62				
3 -----								
1		-4.95						
		.0	-5.05	9.64				
		2.7	-5.05	-3.99				
2		2.01						
		.0	1.78	-.16				
		2.7	1.78	4.66				
4 -----								
1		-89.43						
		.0	-.98	.50				
		1.5	-.98	-.97				
2		.00						
		.0	10.37	-10.32				
		1.5	10.37	5.24				
5 -----								
1		-79.33						
		.0	2.01	-1.63				
		2.7	2.01	3.80				
2		.00						
		.0	8.26	-12.52				
		2.7	8.26	9.78				
6 -----								
1		-14.52						
		.0	.78	-2.57				
		2.7	.78	-.47				
2		.00						
		.0	3.91	-3.04				
		2.7	3.91	7.52				
7 -----								
1		-39.13						
		.0	.53	-.23				
		1.5	.53	.57				
2		-9.65						
		.0	6.19	-8.32				
		1.5	6.19	.97				

8 -----				
1	-33.87			
	.0	3.14	-3.08	
	2.7	3.14	5.39	
2	-5.14			
	.0	5.82	-9.09	
	2.7	5.82	6.62	
9 -----				
1	-9.26			
	.0	4.27	-6.26	
	2.7	4.27	5.27	
2	-2.01			
	.0	1.78	-.16	
	2.7	1.78	4.66	
10 -----				
1	.00			
	.0	5.14	-3.82	
	2.1	.00	1.59	
	4.2	-5.11	-3.75	
2	.00			
	.0	-4.51	10.05	
	4.2	-4.51	-8.88	
11 -----				
1	.00			
	.0	13.72	-7.25	
	2.0	.00	6.40	
	4.2	-15.24	-10.44	
2	.00			
	.0	-3.14	6.77	
	4.2	-3.14	-6.41	
12 -----				
1	.00			
	.0	4.95	-3.99	
	2.0	.00	1.03	
	4.2	-5.30	-4.73	
2	.00			
	.0	-2.01	4.66	
	4.2	-2.01	-3.76	
13 -----				
1	.00			
	.0	4.99	-3.09	
	2.0	.00	2.01	
	4.2	-5.26	-3.66	
2	.00			
	.0	-4.51	8.88	
	4.2	-4.51	-10.05	
14 -----				
1	.00			
	.0	3.86	-4.06	
	2.9	.00	1.50	
	4.2	-1.75	.35	
2	.00			
	.0	-3.14	6.41	
	4.2	-3.14	-6.77	
15 -----				
1	.00			
	.0	9.22	-5.20	
	2.1	.00	4.47	
	4.2	-9.26	-5.27	
2	.00			
	.0	-2.01	3.76	
	4.2	-2.01	-4.66	

Two Dimensional Frame C-C (Static Analysis)/30cm/ /TCC/

SYSTEM

P=1 N=12 L=2 :No of joints and load conditions

JOINTS

1 Y= -4.20 Z= 0.0 X=0.0 :Left foundation joint
 4 Y= -4.20 Z= 1.5
 10 Y= -4.20 Z= 6.9 G=4,10,3 :Top left joint
 2 Y= 0.0 Z= 0.0
 5 Y= 0.0 Z= 1.5
 11 Y= 0.0 Z= 6.9 G= 5,11,3
 3 Y= 4.20 Z= 0.0 : Right foundation joint
 6 Y= 4.20 Z= 1.5
 12 Y= 4.20 Z= 6.9 G= 6,12,3 :Top Right joint

RESTRAINTS

1,12 R= 1,0,0,0,1,1 : All joints in Y-Z plane
 1,3 R= 1,1,1,1,1,1, : Fix foundation joints

CONSTRAINTS

5,6,1 C= 0,4 : Set axial deformation in beams to zero
 8,9,1 C= 0,7
 11,12,1 C= 0,10

FRAME

NM= 3 NL=5 P=1.0

C Member section properties

1 D= 0.30,0.0 B= 0.30,0.0 E=31e6
 2 D= 0.30,0.0 B= 0.30,0.0 E=26e6
 3 D= 0.22,0.0 B= 0.30,0.0 E=26e6

C Span loading Patterns

1 WL=0,-17.84
 2 WL=0,-7.04
 3 WL=0,-18.13
 4 WL=0,-18.88
 5 WL=0,-16.74

C Frame member location

C Columns

1,1,4 M=1 LP=3
 2,4,7 G= 1,1,3,3 M=1
 4,2,5 M=1
 5,5,8 G=1,1,3,3 M=1
 7,3,6 M=1
 8,6,9 G=1,1,3,3 M=1

C Beams

10,4,5 M=2 NSL=5
 11,7,8 M=3 NSL=3
 12,10,11 M=2 NSL=1
 13,5,6 M=2 NSL=5
 14,8,9 M=3 NSL=4
 15,11,12 M=2 NSL=2

LOADS

10 F=0,8.22 L=2
 7 F=0,12.76
 4 F=0,3.15

PRESTRESS

11 D= 0.065, 0.065, 0.065 T=300
 14 D= 0.065, 0.065, 0.065 T=300

C END

TWO DIMENSIONAL FRAME C-C (STATIC ANALYSIS)/30CM/ /TCC.F3F/
SAP80 V85.03

***** FRAME MEMBER FORCES *****

MEMBERS WITH NUMBERS BETWEEN 1 & 32000

MEM #	LOAD #	AXIAL FORCE	DIST I	1-2 PLANE SHEAR	1-2 PLANE MOMENT	1-3 PLANE SHEAR	1-3 PLANE MOMENT	AXIAL TORQUE
1		-107.61						
		.0	-11.68	5.44				
		1.5	-11.68	-12.08				
2		9.63						
		.0	6.58	-10.68				
		1.5	6.58	-.81				
2								
1		-73.62						
		.0	-6.12	9.01				
		2.7	-6.12	-7.51				
2		5.33						
		.0	6.23	-10.23				
		2.7	6.23	6.58				
3								
1		-36.02						
		.0	-11.41	11.60				
		2.7	-11.41	-19.20				
2		2.44						
		.0	1.90	.43				
		2.7	1.90	5.54				
4								
1		-206.48						
		.0	.83	-.43				
		1.5	.83	.82				
2		.00						
		.0	10.97	-12.74				
		1.5	10.97	3.72				
5								
1		-133.83						
		.0	-1.50	1.03				
		2.7	-1.50	-3.02				
2		.00						
		.0	8.53	-13.63				
		2.7	8.53	9.39				
6								
1		-55.52						
		.0	4.90	-3.20				
		2.7	4.90	10.02				
2		.00						
		.0	4.43	-2.59				
		2.7	4.43	9.37				
7								
1		-86.47						
		.0	10.85	-5.13				
		1.5	10.85	11.15				
2		-9.63						
		.0	6.58	-10.68				
		1.5	6.58	-.81				

8 -----				
1	-52.49			
	.0	7.62	-10.16	
	2.7	7.62	10.42	
2	-5.33			
	.0	6.23	-10.23	
	2.7	6.23	6.58	
9 -----				
1	-12.96			
	.0	6.51	-10.02	
	2.7	6.51	7.56	
2	-2.44			
	.0	1.90	.43	
	2.7	1.90	5.54	
10 -----				
1	.00			
	.0	33.98	-21.10	
	2.0	.00	13.40	
	4.2	-36.32	-26.01	
2	.00			
	.0	-4.31	9.41	
	4.2	-4.31	-8.67	
11 -----				
1	.00			
	.0	.46	.39	
	1.0	.00	.62	
	4.2	-1.40	-1.60	
2	.00			
	.0	-2.89	6.16	
	4.2	-2.89	-5.99	
12 -----				
1	.00			
	.0	36.02	-19.20	
	2.0	.00	17.17	
	4.2	-38.90	-25.25	
2	.00			
	.0	-2.44	5.54	
	4.2	-2.44	-4.69	
13 -----				
1	.00			
	.0	36.32	-26.22	
	2.2	.00	13.19	
	4.2	-33.98	-21.31	
2	.00			
	.0	-4.31	8.67	
	4.2	-4.31	-9.41	
14 -----				
1	.00			
	.0	2.62	-1.42	
	2.2	.00	1.46	
	4.2	-2.39	-.94	
2	.00			
	.0	-2.89	5.99	
	4.2	-2.89	-6.16	
15 -----				
1	.00			
	.0	16.61	-15.23	
	2.4	.00	4.36	
	4.2	-12.96	-7.56	
2	.00			
	.0	-2.44	4.69	
	4.2	-2.44	-5.54	

Two Dimensional Frame 2-2 (Static Analysis) /30cm column/ /T22/

SYSTEM

P=1 N=12 L=2 :No of joints and load conditions

JOINTS

1 Y= -4.20 Z= 0.0 X=0.0 :Left foundation joint
 4 Y= -4.20 Z= 1.5
 10 Y= -4.20 Z= 6.9 G=4,10,3 :Top left joint
 2 Y= 0.0 Z= 0.0
 5 Y= 0.0 Z= 1.5
 11 Y= 0.0 Z= 6.9 G= 5,11,3
 3 Y= 4.20 Z= 0.0 : Right foundation joint
 6 Y= 4.20 Z= 1.5
 12 Y= 4.20 Z= 6.9 G= 6,12,3 :Top Right joint

RESTRAINTS

1,12 R= 1,0,0,0,1,1 : All joints in Y-Z plane
 1,3 R= 1,1,1,1,1,1, : Fix foundation joints

CONSTRAINTS

5,6,1 C= 0,4 : Set axial deformation in beams to zero
 8,9,1 C= 0,7
 11,12,1 C= 0,10

FRAME

NM= 3 NL=4 P=1.0

C Member section properties

1 D= 0.30,0.0 B= 0.30,0.0 E=31e6
 2 D= 0.30,0.0 B= 0.30,0.0 E=26e6
 3 D= 0.22,0.0 B= 0.30,0.0 E=26e6

C Span loading Patterns

1 WL=0,-2.93
 2 WL=0,-17.78
 3 WL=0,-4.4
 4 WL=0,-12.22

C Frame member location

C Columns

1,1,4 M=1 LP=3
 2,4,7 G= 1,1,3,3 M=1
 4,2,5 M=1
 5,5,8 G=1,1,3,3 M=1
 7,3,6 M=1
 8,6,9 G=1,1,3,3 M=1

C Beams

10,4,5 M=2 NSL=1
 11,7,8 M=3 NSL=2
 12,10,11 M=2 NSL=1
 13,5,6 M=2 NSL=1
 14,8,9 M=3 NSL=4
 15,11,12 M=2 NSL=3

LOADS

10 F=0,8.22 L=2
 7 F=0,12.76
 4 F=0,3.15

PRESTRESS

11 D= 0.04, 0.04, 0.04 T=300
 14 D= 0.04, 0.04, 0.04 T=300

C END

TWO DIMENSIONAL FRAME 2-2 (STATIC ANALYSIS) /30CM COLUMN/
SAP80 V85.03

/T22.F3F/

***** FRAME MEMBER FORCES *****

MEMBERS WITH NUMBERS BETWEEN 1 & 32000

MEM #	LOAD #	AXIAL FORCE	DIST I	1-2 PLANE SHEAR	1-2 PLANE MOMENT	1-3 PLANE SHEAR	1-3 PLANE MOMENT	AXIAL TORQUE
1								
1		-49.08						
		.0	.25	-.08				
		1.5	.25	.29				
2		9.63						
		.0	6.58	-10.68				
		1.5	6.58	-.81				
2								
1		-42.94						
		.0	-5.50	4.68				
		2.7	-5.50	-10.18				
2		5.33						
		.0	6.23	-10.23				
		2.7	6.23	6.58				
3								
1		-6.02						
		.0	-5.47	10.27				
		2.7	-5.47	-4.48				
2		2.44						
		.0	1.90	.43				
		2.7	1.90	5.54				
4								
1		-91.80						
		.0	-1.13	.56				
		1.5	-1.13	-1.13				
2		.00						
		.0	10.97	-12.74				
		1.5	10.97	3.72				
5								
1		-79.56						
		.0	2.11	-1.61				
		2.7	2.11	4.09				
2		.00						
		.0	8.53	-13.63				
		2.7	8.53	9.39				
6								
1		-15.49						
		.0	.84	-2.84				
		2.7	.84	-.57				
2		.00						
		.0	4.43	-2.59				
		2.7	4.43	9.37				
7								
1		-40.51						
		.0	.88	-.38				
		1.5	.88	.94				
2		-9.63						
		.0	6.58	-10.68				
		1.5	6.58	-.81				

8 -----				
1	-34.28			
	.0	3.39	-3.37	
	2.7	3.39	5.78	
2	-5.33			
	.0	6.23	-10.23	
	2.7	6.23	6.58	
9 -----				
1	-9.28			
	.0	4.62	-6.74	
	2.7	4.62	5.74	
2	-2.44			
	.0	1.90	.43	
	2.7	1.90	5.54	
10 -----				
1	.00			
	.0	6.14	-4.39	
	2.1	.00	2.04	
	4.2	-6.17	-4.45	
2	.00			
	.0	-4.31	9.41	
	4.2	-4.31	-8.67	
11 -----				
1	.00			
	.0	14.06	-8.45	
	2.0	.00	5.88	
	4.2	-14.90	-10.22	
2	.00			
	.0	-2.89	6.16	
	4.2	-2.89	-5.99	
12 -----				
1	.00			
	.0	6.02	-4.48	
	2.1	.00	1.71	
	4.2	-6.28	-5.02	
2	.00			
	.0	-2.44	5.54	
	4.2	-2.44	-4.69	
13 -----				
1	.00			
	.0	6.07	-3.97	
	2.1	.00	2.32	
	4.2	-6.23	-4.31	
2	.00			
	.0	-4.31	8.67	
	4.2	-4.31	-9.41	
14 -----				
1	.00			
	.0	3.46	-3.28	
	2.6	.00	1.20	
	4.2	-2.15	-.52	
2	.00			
	.0	-2.89	5.99	
	4.2	-2.89	-6.16	
15 -----				
1	.00			
	.0	9.20	-5.59	
	2.1	.00	4.04	
	4.2	-9.28	-5.74	
2	.00			
	.0	-2.44	4.69	
	4.2	-2.44	-5.54	

**A SURVEY ON
PRECAST CONCRETE ELEMENTS TECHNOLOGY
(Its production, use and development in Ethiopia)**

Instruction for completing the questionnaire

- Please, put an "X" mark on the space provided to indicate your response where applicable.
- In case where responses other than marks are required, please, write your responses in the spaces provided.
- You may mark more than one as the case may be or use additional paper where the space provided is not enough.

PART I: Identification

1. Identification information
Name of your institution /company/ _____
Profession _____
Position _____
2. What are the specific activities you are currently engaged in?

3. Your relation to the construction industry is as:

☐ Design Engineer /consultant	☐ Construction (Resident) Engineer
☐ Contractor	☐ Architect
☐ Investor /owner/ client	
☐ Others, Specify _____	

PART II: Materials used in the construction industry

4. Type of construction material you use in most of the cases.
☐ Conventional mud & wood (ጥቃቅ)
☐ Reinforced concrete
☐ Precast concrete
☐ Steel construction
☐ Others, specify _____
5. Why you use the type of material you specified in item 4 above?
☐ Traditional use
☐ Easy to use and the technology is simple
☐ Cheaper than other construction materials
☐ easily available
☐ Others, specify _____
6. What type of construction do you recommend for Ethiopia, considering the existing level of development?
☐ Steel construction
☐ Reinforced concrete
☐ Precast concrete integrated with cast in- situ concrete construction
☐ Mud & wood (ጥቃቅ)
☐ Others, specify _____
7. Why do you recommend the type you specified in item 6 above?
☐ Cheap and available (affordable) by the majority of the community
☐ Simple technology that one can use
☐ Most people prefer it
☐ It is appropriate for developing country like Ethiopia
☐ Others, specify _____

PART III: The structural precast concrete and its use.

8. Do you know that precast concrete elements are produced at **PREFABRICATED BUILDING PARTS CONSTRUCTION ENTERPRISE (PBPCE)** at factory level in Ethiopia?
☐ Yes ☐ No
9. If your answer in "yes" in item 8 above, for how many years?
☐ less than 5 years
☐ 5 to 10 years
☐ More than 10 years
10. Have you ever heard of any other precast concrete production center other than PBPCE?
☐ Yes ☐ No
11. Do you think that the use of precast concrete elements is wide spread in the construction industry?
☐ Yes ☐ No
12. If your answer is "yes" in item 11 above, how many buildings do you think are built using precast concrete elements?
☐ 10 or less
☐ 10 - 20
☐ more than 20
13. Have you heard of any noted failure or inconvenience of precast concrete construction in Ethiopia?
☐ Yes ☐ No
14. If your answer is "Yes" in item 13 above what type of failure or inconvenience?
☐ structural failure
☐ Not convenient to install electrical, sanitary fittings
☐ Precast concrete faces are hard to plaster or decorate
☐ It is not easily compatible with cast- in -situ concrete
☐ Others, Specify _____
15. For the inconveniences that were caused, what remedial measures were taken?

16. If your answer is "No" in item 11 above, what do you think, the possible reasons behind?
☐ unawareness of the public
☐ it is damn expensive
☐ the technology is not so simple and flexible
☐ Aesthetically not attractive
☐ Preferred sizes are not available
☐ Afraid of it. It may collapse.
☐ Others, specify _____
17. For what type of construction do you think precast concrete in mostly needed in Ethiopia?
☐ Residential ☐ industrial ☐ Office ☐ all types ☐ Others _____
18. Do you think of any advantage of precast concrete over the cast- in-situ concrete?
☐ Yes ☐ No
19. If your answer is "Yes" in item 18 above, in what sense?
☐ Its cost is cheap
☐ No need of form work
☐ the quality of product is superior
☐ Architecturally attractive
☐ The speed of construction is fast
☐ others, specify _____

20. Do you think the type of the existing structural elements produced in Ethiopia are not sufficient?
☐ Yes ☐ No
21. Do you feel that there is a need of producing other preferred structural elements?
☐ Yes ☐ No
22. If other sizes of structural elements are to be produced, do you expect, high demand for precast concrete?
☐ Yes ☐ No
23. Generally, in your opinion, what measures should be taken to promote the use of precast concrete in Ethiopia?
☐ Improve its design, and avail preferred sizes
☐ Raise public awareness by circulating information (pamphlets, advertisement. . .)
☐ Provide the elements cheaply through government subsidy in order to promote the technology
☐ Under-take appropriate research for its development in collaboration of higher technical institutions
☐ Coordinate the designers, precasters and the end users to work together towards one end
☐ Others, specify _____
24. In your opinion, who should take the initiative to enhance the develop of precast concrete technology?
☐ The government through the Ministry of Works & Urban Development
☐ Cooperation of the concerned institutions (consultants producers, contractors, A.A University) coordinated by the Science & Technology commission
☐ The Prefabricated Building Parts Construction Enterprise
☐ Professional associations of Engineers, architects, etc.
☐ Investors, contractors
☐ Any interested researcher
☐ Others, Specify _____
25. Do you think that precast concrete can be used effectively for special Civil Engineering works other than building construction in Ethiopia?
☐ Yes ☐ No
26. If you answer is "Yes" in item 25 above, for what purpose?
☐ Bridges ☐ Poles
☐ Culverts ☐ Pipes,
☐ Road side curbs ☐ Others, Specify _____
27. Do you have any comment regarding the use of precast concrete in Ethiopia?

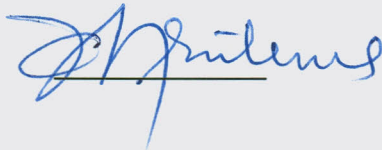
THANK YOU FOR YOUR COOPERATION

Declaration

I, the undersigned declare that this thesis is my original work, it has not been presented for a degree in another University and that all sources of material used for this Thesis have been acknowledged.

Name: **Gutema Bulto W.**

Signature



Place: Faculty of Technology
Addis Ababa University

Date of Submission: June 20, 1998