A STUDY
OF PRECAST REINFORCED CONCRETE SKELETON FOR LOW-COST HOUSING

A Thesis Submitted to
the Faculty of Graduate Studies and Research
in Partial Fulfilment of the Requirements
for the Degree of Master of Architecture

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..... *To my Wife*

CONTENT

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ABSTRACT

This thesis is a survey of the precast reinforced concrete skeleton system used in low-cost housing (SPCSS), which has widely spread to different areas of the world, but less studied. The thesis includes three major parts: 1) the development of SPCSS; 2) the design, performance feature of SPCSS; and 3) cases studies.

The development of SPCSS traces its origin as the structure of prefabricated houses for the housing shortage after the world war in Europe to its spread to developing countries for low-cost housing.

Design and performance study focuses on its features related to low-cost housing -- its special considerations and key points in design as a small component system, its acclaimed system performance features.

Case studies surveys 15 typical cases. Each case includes general background of the system, system design, comments following the design consideration and example of its application.

RÉSUMÉ

Cette thè se est une étude sur le béton renforcé prémoulv SPCSS qui a été utilisé depuis la premier guerre mondiale mais qui u'a pas été très étudié. La recherche comprend l'histoire du développement du SPCSS, sa création, les caractéristiques de performance ainsi que les études des cas divers.

L'origine du développement de SPCSS remonte à l'après-guerre quand il y eu une pénvrie d'habitations; on innova en evrope la structure préfabriquée de maisons jusqu' à son essor et sa commercialisation dans les pays du tiers-monde pour l'habitation à loyer modique.

Le design et la performance se concentrent sur les caractéristiques reliées à l'habitation à loyer modique. Ils étudient dans le design d'un système de petits composants ainsi que les tráits reonnus de la performance.

Il ya 15 cas étudiés. Cela inclut le système de formation général; le système dudesign, l'évaluation suivant la réflexion du design et le prototype de son application.

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INTRODUCTION

INTRODUCTION

THE RESEARCH TOPIC:

As an alternative to the traditional materials for low-cost housing, concrete components are now being used more and more and their use is spreading to every part of the world. It is envisaged that this trend will continue in the coming years.

One of the concrete component system used in the housing construction is precast concrete skeleton system, which basically consists of posts and beams to form a frame. According to their application to different housing types and technological level of construction, skeleton system can be classified into two types.

The first types of skeleton system is mostly used in high-rise or apartment buildings having more than four storeys. This kind of building development with large and heavy components, is usually undertaken by government or big contractors and requires good construction conditions. The system in this group is good for a batch and repetitive construction processes. End-users rarely take part in building design and construction.

The second types of skeleton system, consisting of relatively small components, is used in structures having less than four stories, and the majority of these are one or two storey low-cost houses. It usually appears in the housing process in which building components are made by small manufacturers and bought by the users, who possess no prior construction experience or skills, to build their own houses. This type of system is called the small precast concrete skeleton system, which is refereed as SPCSS in this thesis, and is the subject of this study. Many different types of SPCSS have been developed over the years in different countries, this study will focus on those systems that are specially appropriate for and applicable to low-cost housing technology.

OBJECTIVE AND SIGNIFICANCE OF THE STUDY:

As one of the earliest proposed prefabricated systems for low-cost housing, SPCSS has been developed extensively as early as the 1940's and has been used in different places. But as a component system having special features, it has never been comprehensively studied and summarized as the subject of an independent study. It has long been an attractive low-cost housing system and has been proposed repeatedly since it was developed, but relevant studies are mostly scattered and fragmented.

The intention of this thesis is therefore to fill this gap and to do a study leading to a better understanding of SPCSS. By means of a literature survey, it intends to summarize and review the previous work done in the field, to find out the design features of SPCSS, to analyze its function and performance and to collect the valuable information on different systems.

The SPCSS was developed as one part of the system building movement which dreamed of mass producing houses in factories similar to the way automobile and aero-planes were produced. Its development process recorded the effort of our time in struggling with the housing shortage by means of a building system. Therefore, the significance of this study is not limited to SPCSS itself; it is also representative of the different aspects of the industrialized housing technology.

ORGANIZATION OF THESIS:

The main body of the research consists of two parts -- general review and particular case studies related to SPCSS. The two parts complement each other. By bringing together and analyzing the systems developed in different places at different times, the case studies intend to give a detailed overview of the previous work done and provide a convenient reference for future design and further study of SPCSS. The general review is presented to describe the origin and development of SPCSS as well as integrated knowledge on SPCSS.

The thesis begins with the general study, which includes 1) the historical review; 2) the design and performance of SPCSS.

1) The historical review: this review trace the development process of SPCSS within the background of a changing attitude to the solution of low-cost housing. By this review, the cases from different places and different times can be integrated.

2) The design and performance of SPCSS: it includes a) design study which focuses on the design essential related to SPCSS; b) the performance analysis which gives a critical review on the performances of SPCSS, especially its acclaimed features

The general study is followed by individual case studies. In the case studies, each case is provided with its background, illustration of components, evaluation of properties and example of application.

Lastly, a summary of the previous section is presented. It indicates the key points to the design of SPCSS, and differentiates the inherent advantages of SPCSS from its designed advantages. It also points out the major drawbacks of SPCSS and gives suggestions about its application.

PART ONE
GENERAL STUDY

- **The Development of SPCSS**
- **Design Study & Performance Analysis of SPCSS**

CHAPTER ONE

THE DEVELOPMENT OF SPCSS

This part of the thesis will be devoted to a general historical review of the development of SPCSS. Since the historical data on SPCSS is not confined to one country but widely dispersed, and is difficult to obtain or has in many instances never been printed, the writing of this review presented the opportunity of bringing within the covers of a single work the substance of much data that would otherwise have remained scattered and unorganized.

The emergence and development of SPCSS is not a single event, but has been closely bound up with social factors and conditions of productivity. Therefore, the author of this thesis has elected to cover the field from a wider point of view, including the social background of SPCSS's development. In a work of this breadth encompassing such a long period dating from the end of last century, many events will unavoidably be omitted, but this work is an attempt to highlight those events which are considered to be landmarks in the development of SPCSS.

1. GENERAL BACKGROUND: THE EARLY PERIOD

The "housing problem", which was created by the inability of capitalism to ensure adequate housing conditions for all levels of society, was first identified in the middle of the last century[1]. However, in the 19th century, solutions to the "housing problem" were largely concentrated on inexpensive methods of financing rather than on new technology[2]. At the turn of the 20th century, especially after the First World War, with the increasingly severe housing shortage, it was recognized that the imbalance between the housing demand and the ability of the traditional methods to supply housing was the root of the housing problem. From the development of new methods of manufacturing, which introduced mass production of complex artifacts, the pioneer architects, builders and politicians of the time were greatly inspired and saw the possibility of providing adequate housing for all people: this was to be done by means of technical innovation in the housing industry. Central to this interest was the ambition of mass producing houses in the same way as many other products[3].

The underlying principle of the factory-made house is the preparation by mass production of as many parts and units as possible, thus reducing erection time and site work to the bare minimum. By using this principle, it was estimated that the speed of house construction would be faster and the price reduced, so that the housing problem would eventually be solved. This was the general social background against which SPCSS came into being. SPCSS therefore, was not a single event but a part of the movement leading to the industrialization of housing.

Before SPCSS was introduced into practice, there were two architects whose works are worth noting. The first one was W.H.Lascelles of England with his patented "Improvements in the construction" which dated back to as early as 1875. Lascelles' intention was "more particularly to reduce the cost of small houses or cottages, and to

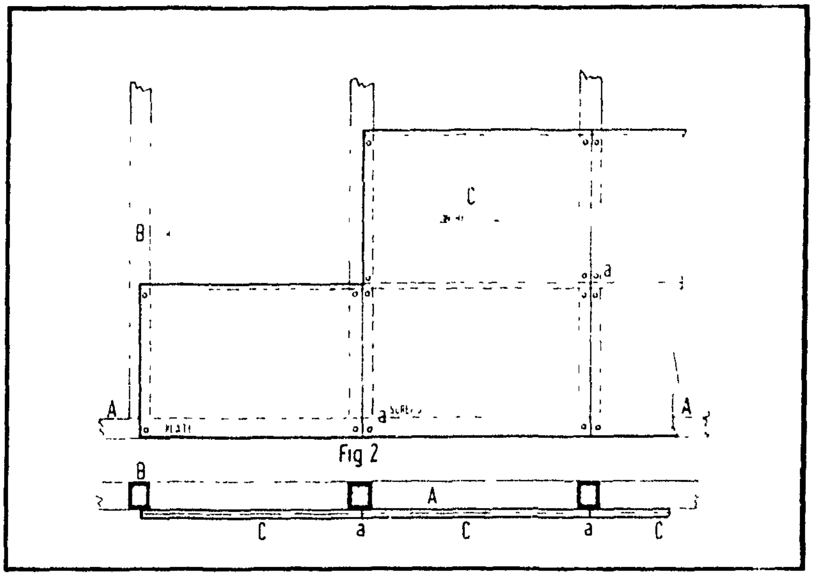


Fig.1.1 The basic ideas of Lascelles' "improvements in the construction of building", 1875 (Morris, 15)

facilitate the construction in such a manner that they may be erected for the most part with unskilled labor and in a short space of time". To that end, he devised a system of prefabricated construction based on precast concrete cladding panels fixed on a previously erected structural frame, as shown in Fig.1.1[4]. At the same time, Mr.Lascelles suggested that the dimensions of his precast panels should be limited to the maximum weight capable of being manually handled on the scaffolding by two men[5]. This probably is the earliest recorded system of small precast concrete components, and its basic form was very similar to the SPCSS appearing later in the same country.

The second architect worth mentioning in the early period was Le Corbusier. He was the first architect to study the potential of the precast concrete skeleton being used in low-cost housing and to constantly promote it*.

As early as 1914, Le Corbusier worked out a concrete skeleton model called the

* Corbusier's knowledge of the concrete skeleton model most probably derives from his teacher, Auguste Perret, who was the first person to skillfully use the concrete frame.(Morris 41)

"Domino"**. In this proposal, the structure of the house had been reduced to its most basic level, and the architectural characteristics of the skeleton and its potential in the field of low-cost housing had been analyzed very comprehensively. To sum up the main points, they are as follows:[6]

(1) The separation of structure and infill materials: This allows to use any kinds of in-fill wall material. The structure is relatively independent and can be mass produced.

(2) Fast construction but low-cost: due to the mass production of components and the specialization of workers, on-site operation is reduced and technology is simplified, so that the speed of construction can be fast and cost can be reduced.

(3) Free plan: Since they are no longer load-bearing, the interior partitions do not need to be precisely superimposed from one story to the next, but can be freely disposed of at will. The eternal conflict between wall and window is also solved.

Ten years later when Corbusier finally got an opportunity to actually use skeleton in a workers' housing project known as the Pessac houses, he did not completely implement his idea. The most obvious failure of this Project was the much higher cost than anticipated[7]. Since then, the Domino proposal stayed mainly in the realm of architectural appreciation and did not go into practice.

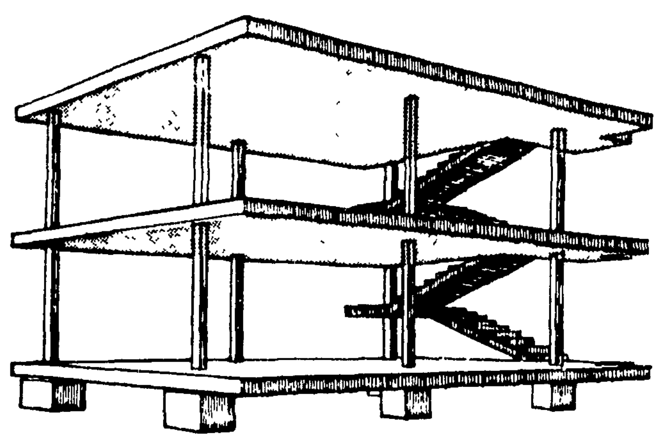


Fig.1.2 Domino system, 1914 (Baker, 631)

** In 1902, the concrete frame had been used for apartment building, but it did not lead to SPCSS. (Coleman 114)

2. THE EARLY DEVELOPMENT OF SPCSS --- ENGLAND

As stated above, from the beginning of this century, the severe shortage of houses in all countries led to a wide effort to produce mass housing by any suitable means. Architects and politicians lay their hope on prefabrication, believing that houses could be made in factories, like cars and aeroplanes. However, against this general background, the evolution of prefabrication in various countries followed different paths according to their own conditions. While the other European countries, for example Germany was exploring large monolithic concrete slabs construction system[8] and America was largely building timber houses, Britain developed the SPCSS.

Being optimistic about prefabrication with all its benefits in terms of cost, improved quality and rapid production to satisfy the great housing demand, particularly low-cost housing, the British government heavily subsidized a "war time housing programme" during the interwar period and years after the Second War. With the help of this promotion, many prefabrication systems were explored.

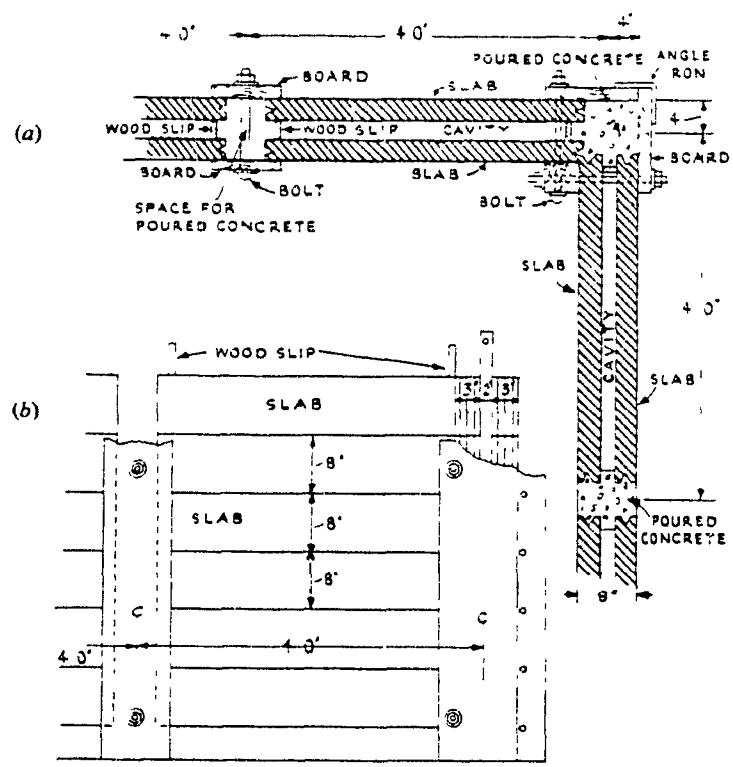
The priority to develop new systems during that time was to improve the construction method of the wall; that is, to substitute the method of laying brick walls with new methods within the traditional design concept. This was because the low efficiency and extensive on-site work made the brick construction the most costly part in housing construction[9].

Theoretically, it has been recognized that in order to reduce the erection time and site work to the minimum, the ideal of prefabrication was to increase the size of factory made units to the maximum, but this requires good transportation and construction conditions. In this aspect, Britain met several obstacles: the railways were run down, there was a shortage of trucks, road transport was poor; good machinery for producing and erecting components was not developed and there was also a lack of skilled labor[10]

Therefore, many concrete systems developed during the inter-war period have been found to be too heavy and large for convenient handling[11].

Despite many failures, a system called "Cavity wall" was approved as the improved construction method intended to be suitable for the conditions of the time. Since this is the predecessor of the SPCSS developed later and was a widely used system of the period between the two wars, a short description of this system is necessary here.

The main characteristic of the "cavity wall " system was that the walls were formed with two thin slabs separated by a cavity. This not only reduced the concrete consumption, but also provided the house with better thermal and acoustic performance. To provide



(a) Plan looking down
(b) Elevation showing method of erection

Fig.1.3 The Duo-slab system of concrete walling (White, 55) adequate support for the slabs and in order to make the slabs smaller, poured concrete posts were laid at certain intervals. Fig.1.3 shows the "Duo-slab system" developed in the early twenties by Airey and Son Ltd. , which was a very successful example.

After the second world war, in many European countries an even more serious rebuilding task coupled with a critical shortage of skilled labor and traditional material contributed to the development of the most important sector of the building industry --- building with concrete. In Britain, the "cavity wall" was developed into fully precast system --- the precast skeleton system. In the new system, precast posts were used instead of the poured-in ones. It remained the significant feature of its predecessor --- space between posts was small so that each post and wall slab could be smaller and lighter. Criteria for the weight and size of the components was set up and widely recognized. For example, it was stipulated that the components should be able to be handled by three persons[12] The Woolaway system of this time was a good example of the new systems. Not only were there small spaces between the posts, aerated concrete was also used to reduce the weight. All the components in this system including the wall panels could be handled by one or two persons (Case study 15).

According to incomplete statistics***, there were at least 122,000 SPCSS houses built by 1956. Among them, the Airey system (fig.1.4) was the most successful one. It came from the same company known for the Duo-slab system, and its development from the cavity wall system was evident. Therefore, it was sometimes called the New Duo-slab Airey house. However, its production process differed radically from that of the firm's Duo-slab system. It was no longer a simple process of site casting but a very organized complex of factories producing precast components in various parts of the country[13].

*** Here only seven types of houses which were investigated during 1981-83 by Building Research Establishment were counted, actually there were more than seven types of systems developed.

Fig.1.4 Airey houses at Chingford **(Finnimore, 210)**

The system consisted essentially of precast dense concrete posts and slabs, of small enough dimensions for all pieces to be manually handled. This was considered essential for the many small, scat ered rural and semi-rural sites that were numerous in Britain. The posts were of single storey height, 4in. x 2.25in. in section, and were placed at 1ft.6in. between centers. They were connected across the house by first floor joists. Thus a series of light portal frames was set up to which similar frames could be dowelled to form the upper storey. From 1945 up to 1955, a production programme of some 26000 houses was carried out. About 20000 of this total were of the rural type, hence the original aim of the system --- to provide an eminently manually handleable construction for relatively small and scattered sites was realized[14].

The Airey houses are sufficiently typical of concrete precast skeleton systems in general in the post-second world war years to avoid the necessity of describing many others in detail here. Some of the other systems will be introduced in the Case studies.

After 1960s, the situation in Britain changed ---with the higher level of industrialization, improved transportation and construction conditions, and the withdrawal of governmental subsidies accompanied by market change leading to the abandonment of the two story cottage[15] --- SPCSS gave way to the other systems. But in many developing countries, SPCSS began to be adopted as a popular system of construction.

3. THE SPREADING OF SPCSS TO DEVELOPING COUNTRIES --- THE POST 1960S

Reinforced concrete elements used in low-cost housing appeared at first to be unsuitable to developing countries, mainly due to the insufficient concrete supply. After the late 1960s, this situation began to change, and SPCSS has been increasingly developed.

This change --- that of the SPCSS being used in developing countries --- was first brought about by the great increase in cement production in many developing countries (Tab. 1), while at the same time the traditional building materials had become scarce. This condition made concrete to be considered as an alternative material.

Tab. 1. Growth of Domestic Cement Production(1966-1975)[16]

Region or country	1966	1975 (million tones)	Percentage Increase %
Africa	12	23	92
North America	82	90	6
South America	17	34	100
Asia	82	168	105
Europe	176	248	41
world	457	691	51
China	11	30	173
India	11	16	46
Philippines	1.6	4.4	180
Sri-Lanka	0.08	0.393	390

Besides the factor above, there are other factors which contribute to the use of SPCSS in developing countries. The first is the existing conditions which determined the form of the component system, i.e., the poor transportation systems; lack of skilled labor and good machinery for construction; small, scattered factories with relatively low productive ability. Under this context, it was realized that the large industrialized systems were inappropriate and it was necessary to develop small component systems.

Second, in these developing countries, the structural part of a building usually makes up 80% of the total cost, where as in developed countries it makes up only about 40%[17]. Therefore, the reduction of cost of the structural part is extremely important. SPCSS, as a small component system, concentrated the structure in a bare skeleton, while the in-fill part could use any kind of cheap material available.

In the 1960s, SPCSS appeared first in Latin America. At the beginning, systems developed there were more or less influenced by the British systems. Many of them were of the post-panel type[18]. For example this influence can be found in a system called "Sandino" developed in Cuba in 1970's. This system gained its popularity in many socialist countries, particularly in rural areas by means of Cuban foreign aid[19]. Sandino also takes the form of post-panel, but the cavity wall has been replaced by a solid wall, in some cases, sandwich panels.

Fig.1.5 Sandino Houses: its main features are simplicity and the handy dimensions of the components: the panels measure about 50x100cm, the columns have a double "T" section into which the panels can slide. (Segre, 352)

In time, SPCSS in developing countries began to gain its own features. It was realized that producing a house as a complete system --- including structure, wall panels, interior facilities, etc. --- out of factories in the same way as producing automobiles was not affordable for the poor populations of those countries, also concrete consumption had to be reduced due to its high cost.

The change started from the separation of structure and infill part. Soon only the skeleton part was made of precast concrete, locally technical conditions and locally available materials were considered in subsequent SPCSS designs.

Fig.1.6 Sandino workshop in Mozambique (Lwansson, 18)

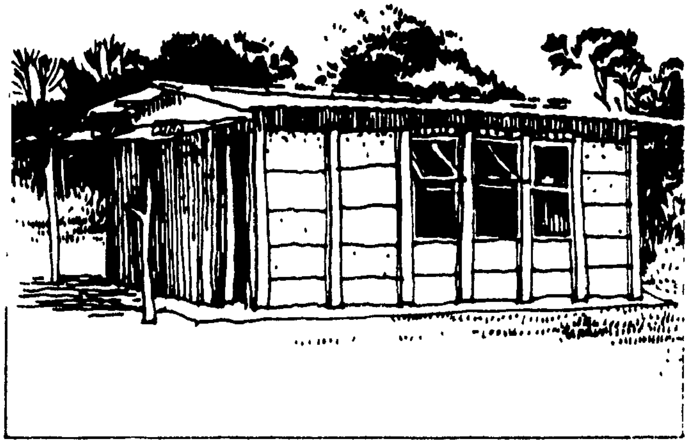


Fig.1.7 Sandino house in Managua
(Mathey, 47)

Fig.1.8 Sandino house in construction
(Segre, 353)

Fig.1.9-10 shows the "VIMA" system of the 1960s developed in the Republic of Argentina[20]. The wall material used to infill the skeleton was a kind of industrial waste instead of concrete panels. Another example is shown in Case Three. This system is called "Apopa" and is developed by the German Appropriate Technology Exchange (Gate) in El Salvador in the 1970s. The conventional building method in El Salvador is adobe construction, which is cheap, climatically suitable and technically simple. But the houses can not resist erosion by rain and collapse in earthquakes. Instead of using other materials such as concrete blocks, burnt clay bricks or wood to replace this building method, they added a concrete skeleton with an asbestos cement corrugated sheeting as a roof to the adobe structure to upgrade it. Thus, theoretically, not only the cost of the house remained moderate but also it was culturally acceptable and kept the advantages of the conventional structure.

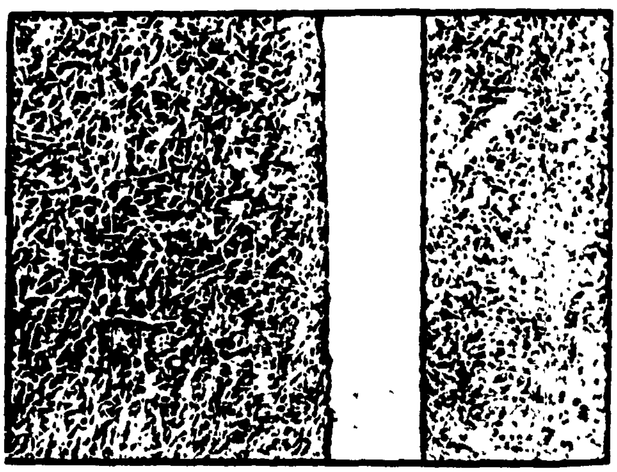


Fig.1.9 The in-fill material used in VIMA system

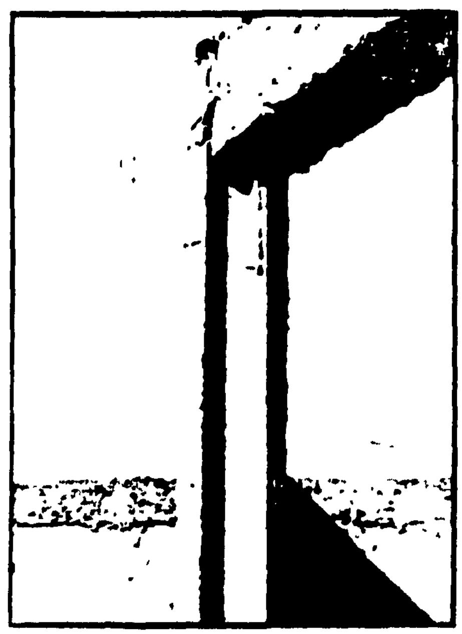


Fig.1.10 The detail of VIMA system (Both: sistemas,81)

A corresponding development after the 60's is that many Third World governments and International agencies are participating in large scale low-cost housing developments with subsidy to the poor. As a cost effective system, SPCSS was frequently proposed for "self-help", "support" houses or "shell" housing projects. The critical reason for its popularity with housing agencies is that SPCSS can provide an efficient durable structure within limited finances, and the rest of the house can be finished by locally available resources --- cheap materials and unskilled labor, usually the users themselves. In the future, this house can be easily expanded and upgraded.

Fig.1.11 shows a housing project in Panama using the "shell housing" method. The shell --- foundation, floor, columns and roof, provided by the housing agency --- needs only to be walled up with different materials according to the wishes of individual families. Expansion can be made as income permits. Labor intensive methods were used in the new communities for such jobs as installation of water lines and for shell house construction. This expanded the employment opportunities for people in the communities[21].

In the 70's in India, and the 80's in China, SPCSS was introduced by public or government institutes. This system was promoted for its strength, durability, rapid speed in construction, and as an alternative to conventional material. Its application has become more specific, for example, as anti-seismic, flood and wind structure and as the structure for mixed use housing which needs flexibility. This can be seen from case 3,5,7,8.

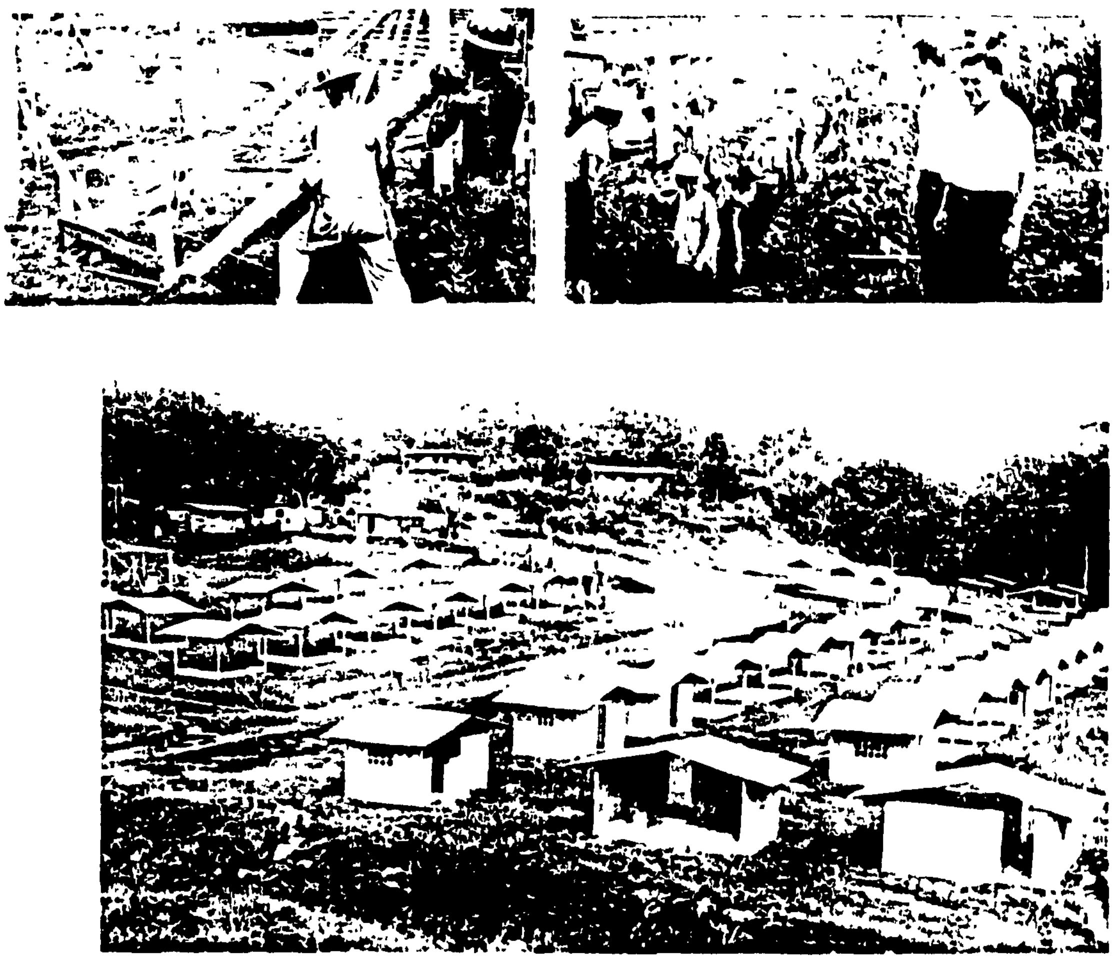


Fig.1.11 Shell housing project in Panama (Foundation, np.)

The most recent successful example was the "Grameen Bank Housing Project" in Bangladesh, which won the 1989 Aga Khan Architectural Award. This housing programme was developed from the "Grameen Bank Project" which was started in 1976 to raise the incomes and the standard of living of the most disadvantaged sectors of the rural community in Bangladesh by providing access to credit. The same policy extended to the housing loan aiming at improving the bamboo and reed mats shelters which were vulnerable to high winds and flooding. The G.B. housing loan provided a basic housing structure -- a roof to be covered in corrugated iron sheeting supported by four reinforced concrete columns -- the structure was simplified so as no professional skills were needed. On this basis, the bank members could develop the house to suit the local context and used available additional resources to add improvements over the years. To pay back the loans, the borrowers set up income generating activities, such as weaving and the production of other home manufactured goods. From 1984-1990, 59,000 Grameen houses were built[22].

Since early this century until now, SPCSS has developed from a supporter of wall panel in post-panel system to barely independent structure with any in-fill material in the wall, from a complete system of house to a partially prefabricated system, from a technical solution for housing shortage to an element combined with social economic development of housing program . All these changes, however, have not changed SPCSS's basic feature: it is a small component system designed for self-built housing under simple construction condition.

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CHAPTER TWO

DESIGN STUDY & PERFORMANCE ANALYSIS OF SPCSS

There are two sections in this part of the thesis. The first section focuses on the design problems related to SPCSS and develops some important criteria for the component design, which is also a frame of reference for evaluation in the case studies. The second section reviews the performance of SPCSS, especially its acclaimed features.

1. DESIGN STUDY

The arrangement of the design study will be as follows: first, there is the study of the general characteristics of the component systems for low-cost housing, with emphasis on characteristics of small component; second, there is an attempt to answer the question as to what the small component means in terms of the design considerations of SPCSS; third, there is the study of the special physical form of SPCSS.

1.1. THE CONCEPT OF SMALL COMPONENTS

The major feature that makes SPCSS different from other systems is that it is a small component system. Small component is a broad concept related to low-cost construction. It does not only refer to the size of component but also to the practicality which provides to the whole building process.

In his book Industrialized Housing, I.D.Terner gave an interesting and accurate description of the small component:

> (The small component) is principally characterized by a coordinated, simple, and non-assembled system of components. Such technology gains its greatest potential when it can be utilized not only by professional contractors, but also by self-help builders who possess no prior construction experience or skills.... [1]

The most typical small component is hollow block which not only is small and simple, but also lends itself to a range of manufacturing techniques. As indicated by Terner, the blocks may be produced initially by hand, and without any changes in configuration, can be fully mechanized and mass produced[2].

Generally speaking, the term "small component" also indicates "simple fabrication equipment ... or simpler and lighter erection devices or pieces small enough to be handled by manpower alone"[3]. The small component is a product which, in terms of development, lies between the traditional construction method and modern prefabrication technology. On the one hand, it uses prefabrication technology to meet the great demand for building components that the traditional methods can not meet, and exploits the many kinds of available sources in response to the shortage of traditional building material. On the other hand, it adapts as well as possible to the conventional building form and process. Therefore, the system using small components differs from the many building systems in developed countries which often totally change the traditional building process and organization. It is of practical application when transplanting the idea of industrial technology to low-cost housing in the developing areas. Therefore, the small component is the essential concept in the design consideration of SPCSS.

1.2. DESIGN CONSIDERATIONS OF SPCSS

The design considerations of SPCSS in terms of the characteristics of small component is the focus of this part. Therefore, although the factors listed below were mainly referred to "Master list*" from IF, it has been sort out in different order to serve its own purpose. The aim of this part is to establish some important criteria in design of SPCSS. These cretria will also be applied in the evaluation of the cases in the following chapter.

—— Manufacturing Considerations

—— Transportation Considerations

—— Construction Considerations

—— Architectural Performance

—— Economic Considerations

* Master list published in IF provide a framework for presenting the information about closed systems will be provided. (Roger Camous, 57-60)

1.2.1 Manufacture Considerations

For SPCSS, the principal consideration is that the components must be easy to make. Although advanced technology may be applied to a particular system developed in a certain area, for most SPCSS systems on the whole, they should be able to adapt to different technological levels, especially to the lower level of technology.

To state it in concrete terms, manufacture considerations include:

(1) Components should be able to be made both by hand and by simple machinery: it means the components can be applied under different situations. For example, the hollow column in the Singh system (see case 4) was made by galvanized zinc tube manually which is suitable under rural conditions; the same component in Xinti system (see case 7), was made by a centrifugal machine which had been used locally.

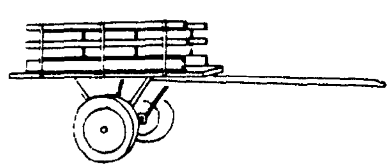
(2) Components should be simple in shape: the simplicity of components make the manufacture of component easier for unskilled labor. But, it is hard to draw a line of demarcation between simplicity and complexity. Generally speaking, the rectangular shape is easy to control. The more shapes add onto it, the more complicated the form becomes.

The manufacture of columns with corbels may show clearly the relationship between the shape of the component and its manufacture. Columns with corbels on one side or on two opposite sides are easily cast in flat beds. If corbels are required on three sides, box forms are set atop the upper side of the column as it lies in the bed. For corbels on the fourth side, there would be quite a little trouble in making them[4].

1.2.2 Transportation Consideration

SPCSS is usually made by small manufacturer who is usually close to the site for the reason to reduce transportation work.

With regard to its application in rural areas, SPCSS should be easy to transport by normal transportation devices used in the countryside, such as push-cars, tractors, etc.[5] (Fig.2.1) Usually, components in SPCSS are relatively small and there is no problem in the load-bearing capacity in these vehicles to transport them. The main concern is the damage of component due to poor condition of road. For example, If column are too long, such as the two storey high, it may gee cracking during transportation.



ANIMAL DRAWN CARTS

Carts suitable for pulling by donkeys, horses and oxen are available All are fitted with pneumatic tyres

	Floor size (m)	Max load (kg)
Donkey cart (with shafts)	1 60 x 0 95	400
Horse cart (with shafts)	2 00 x 1 15	1000
Ox cart (with draught pole)	2 00 x 1 15	1000
Forage cart (low loading platform)	2 60 x 1 70	1500

Fig.2.1 There is no problem in load-bearing capacity in the simple vehicles (Boyd, 145)

1.2.3 Construction Considerations

Since the number of components in a SPCSS are relatively few and the construction process is relatively simple, the main concerns for its construction are: first, whether the components are easy to be moved and assembled when there is a lack of mechanical devices; second, whether the design of the system facilitates its construction. For the first concern, an approximate result can be achieved by examining the weight of the components. For the latter concern, a simple judgement can be made by investigating the number of components and the construction speed.

(1) Criteria for weight:

In different areas, the criterion of maximum weight for manually handled components is different. According to the study by the International Labor Office, in developed countries this criterion is mainly based on health and safety considerations; in most developing areas, usually it is set according to the maximum load-bearing capacity of the human body. By reviewing and comparing the criteria in different places, it is determined that 50kg/per person is the maximum weight for manual handling in terms of health and safety considerations, and 80kg/per person is the maximum load-bearing capacity of human body[6]. The maximum number of persons involved to move and assemble a component should be not more than four as in the experiment done by Marleen Iterbeke[7]; therefore, it is estimated that the heaviest small component should be between 200kg (health and safety criterion) and 320kg (heaviness criterion), and components exceeding this limit would be regarded as not convenient for construction.

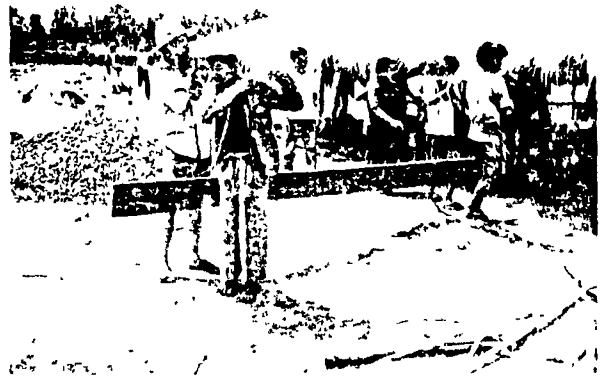


Fig.2.2 Components can be carried by four persons (Iterbeke, 5.2)

(2) Equipment used in construction:

Simple mechanical devices, especially lifting devices, are usually required during construction even if the component can be manually handled. For example, the lifting devices used in daily farming work may be utilized if the system were being used for farmers' houses.

(3) The number of different kinds of components in a system:

Normally, the fewer the different kinds of components, the simpler the system. The simplicity of a system not only means that the production of components is less troublesome, but it also means that the skills required for construction would be fewer, thus more suitable for unskilled labor. Also, the smaller the number of different kinds of components, the more routine work there would be, and the simpler the installation work.

(4) Construction speed:

Increasing the construction speed is one of the main reasons for using precast components. Moreover, construction speed also reflects the simplicity and rationality of the system design of SPCSS, because the speed of construction can only be guaranteed by the rational design of the system, especially the design of connections between the components.

1.2.4 Architectural Performance

The physical performance of a house using SPCSS is not the consideration here, because SPCSS is a pure structure and physical performance can not be measured without in-fill material. What is being considered here is only the architectural performance of SPCSS. For SPCSS, this means the flexibility for the system, and there are mainly three aspects:

(1) Whether or not the structure allows the use of different infill materials.

(2) Whether or not the system allows different architectural layouts.

(3) Whether or not the skeleton itself can be extended horizontally and vertically

1.2.5 Flexibility in Application

Flexibility in application is critical for mass production and low-cost. From previous practice, the successful systems have been usually the "open" ones. The "open system" for SPCSS means that one system can be adapted to different types of buildings and it also means that the components in a system are inter-changeable with other components or can be combined with others. It can be measured as follow:

(1) Total interchangeability: there are no special connections between components. Each component in the system can be used independently with other systems.

(2) Semi-interchangeability: The main structural part in the system is not interchangeable, but roof or floor may use different components.

(3) Zero interchangeability: The whole system is closed.

The factors listed above are only some common criteria. Some other factors are also important in design, but have less common character, therefore are not presented here. Such as the consumption of materials is a critical part of cost, but it is related to the structural features of the system, for example, the anti-seismic or anti-flood system will naturally consume more materials. Therefore, many systems are not comparable in these aspects. Actually, the design of low-cost housing system is a systematic work related to local condition and specified project, design consideration will be more complicated in practices.

1.3. THE KEY POINTS IN THE DESIGN OF SPCSS

There are some key points in the design of SPCSS, which shape its form and embody the design consideration. They are studied in this section.

1.3.1 The Type of SPCSS

SPCSS consists mainly of beams and columns. Theoretically speaking, it can adapt to different plans --- round, triangular or rectangular. But round or triangular plans are seldom used. Fig.2.3 shows a round skeleton housing structure designed in the 1940s, but it has never been widely adopted[8].

For a rectangular plan, there are three types of systems:

(1) Wall and floor frame

This type of frame was developed in India, it is similar to a kind of ribbed slab called the "Ucopan" used in the same area in 1960's (Fig.2.4). It intended to save concrete but is complicated for manufacture and construction.

(2) The "L" shaped component combines column and beam together

This kind of system has the advantages of fast assembly and good monolithicity because it has fewer joints. It especially facilitates the construction of pitched roof houses. But it would encounter problems in manufacturing and transportation and the components are rather heavy for self-building. It appeared in the 1940s for low-cost housing projects (Fig.2.5) but has never attracted much attention[9].

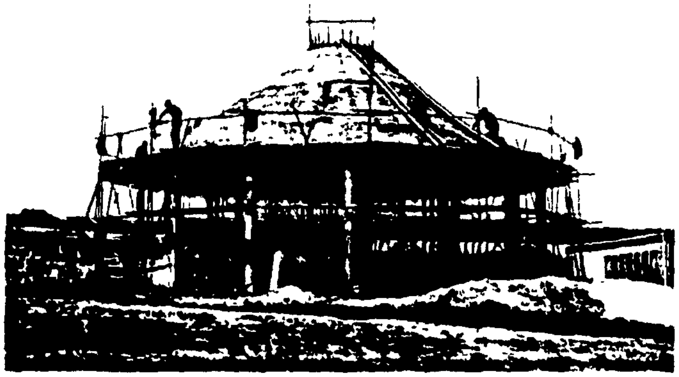


Fig.2.3
Round Plan Skeleton, 1914
(A circular, 79)

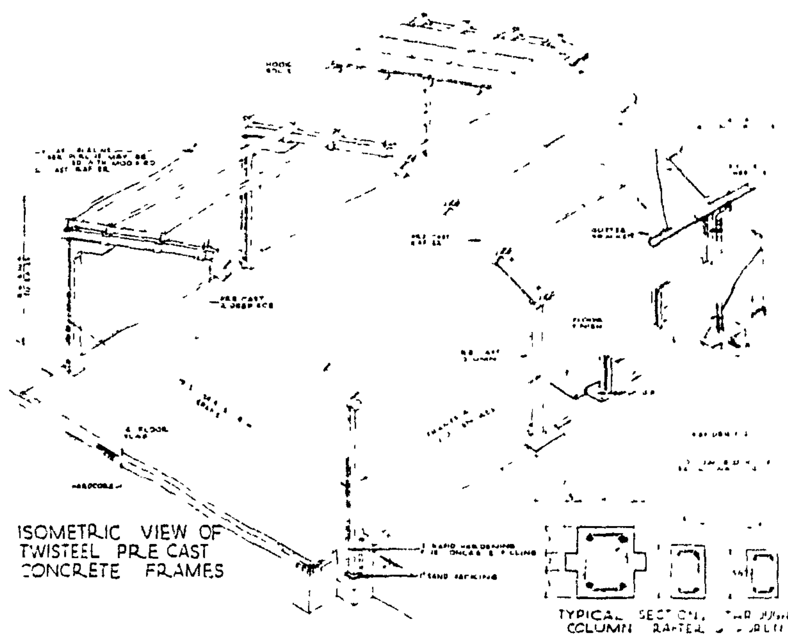


Fig.2.5
L shape component skeleton, 1940
(A system, 393)

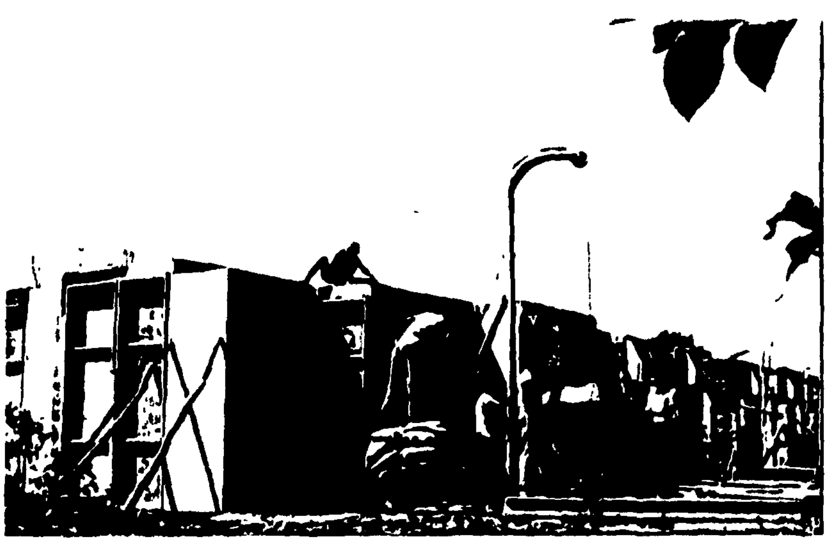


Fig.2.4
UCOPAN used in South Asia
(Zielinska, 9)

(3) Post-and-beam system

Components in the post and beam systems are relatively simple, normally with a rectangular, straight form. They are easy to make and have more flexibility in application. Therefore, this system is the most popular. The so called typical SPCSS refers to this. There are several basic types as shown in the following figures:

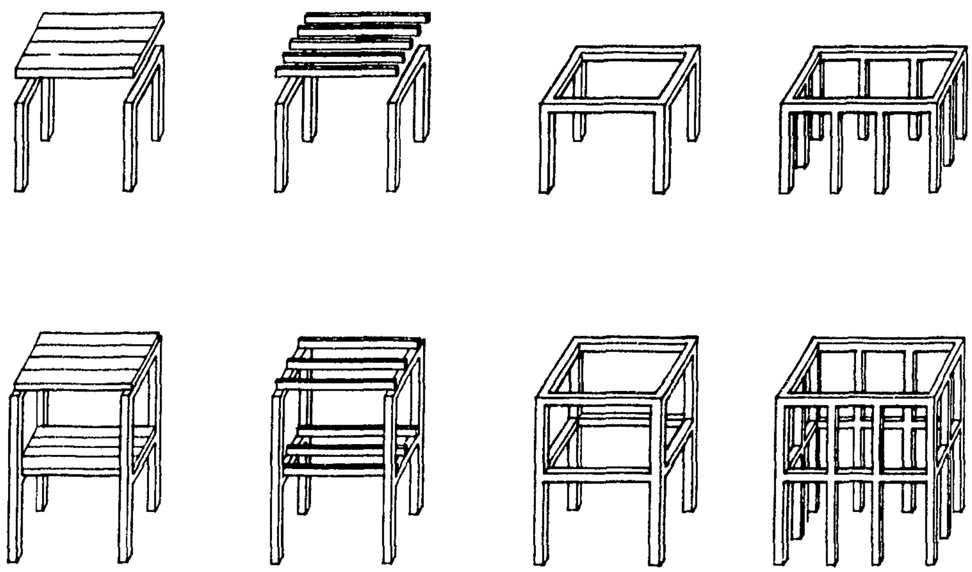


Fig.2.6 Basic types of post-beam system

1.3.2 Column Grid and Component Design

The critical part of the design of a SPCSS is the choice of column grid, the design of its columns and connections. In accordance with different requirements, different designs are used so that a SPCSS will acquire its special characteristics such as speed of construction, anti-seismic quality, etc.

(1) Column grid

Compared with the normal concrete frame system, SPCSS has a relatively small column grid, sometimes it is called the "small column grid skeleton system"[10]. The reason for this is that by reducing the column grid the dimension and weight of the columns can be reduced. However, there should be a limitation in reducing the dimension of the grid. It has proved to be uneconomical for the dimension of the grid to become too small, because the column can not be reduced beyond a certain dimension, otherwise, the structural capacity of concrete will not be brought into full play. The following formulas will explain the situation clearly.

Fig.2.7 is a typical layout of a skeleton: In this structure,the strength of compression of the column (N) is the direct ratio (∞) of b^2

i.e. $N \infty b^2$

The stability(S) of the column $S \infty b^4$

The bending strength(B)[11] $B \infty b^3$

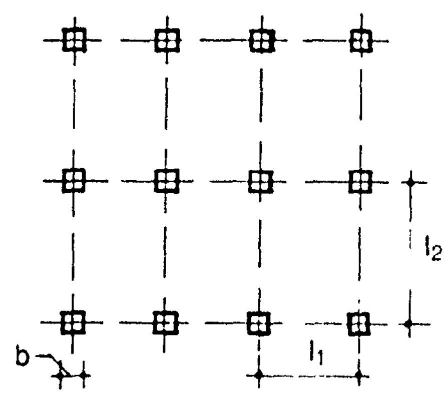


Fig.2.7 Typical layout

If l_1 and l_2 change in proportion, the compressive load would be the direct ratio(∞) of $l_1{}^2$ and the bending moment which is caused by wind load would be the direct ratio (∞) of l_1

Therefore, it can be concluded that, when l_1 is reduced, "b" will be reduced too, and eventually the size of the column will be controlled by its stability and not by its loadbearing ability , so that the material can not fully perform its load bearing function. From this point of view, the space between columns should not be too small.

(2) Footings

Various foundation can be used for SPCSS, but pocket footing is the most popular. There are two advantages in using pocket footing. The first is that the placing, plumbing and fixing of the column as well as the subsequent filling of the pocket with concrete are simple procedures and require less time. The second is that this method is the least sensitive to inaccuracies and errors occurring during construction[12].

The verticality of columns and their accuracy of alignment to suit the grid are of major importance. A typical design embodying these consideration is shown in Fig2.8. With this footing, a correct position can be achieved by using wedges in two horizontal directions and an adjusting bolt, bearing on a metal plate[13].

In general, pocket footing is recommended. But this footing usually is the heaviest one in precast system, it is also acceptable to use cast in-situ footing.

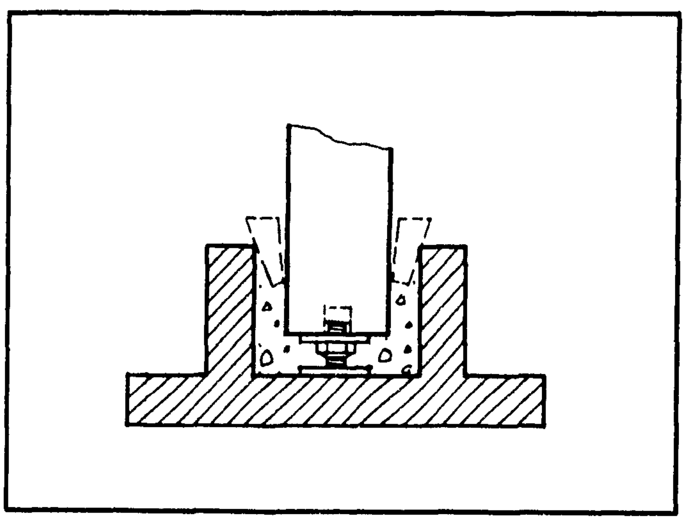


Fig.2.8 Typical pocket footing (After Haas, 33)

(3) Columns

In the conventional concrete frame structure, the columns are usually up to more than two storey high so as to reduce the site work[14]. But these columns are too big and heavy for low-cost housing construction. Therefore, in most SPCSS, columns are only one storey, maximum two storey high.

The most commonly used column is the rectangular tie column. This kind of column is relatively economical and easy to make[15]. Small holes are usually pre-laid on the column for laying the steel bars, which are used to connect the column with the infill wall. For the cavity or solid wall construction method, on the two opposite sides of column, tongues or grooves were made for fixing the wall panels.

A major task in the design of the column is to make it simple and light. As mentioned before, the component can be up to 200-320kg. If the density of concrete is 2500kg/m^3, the volume of a column will be 0.08-0.128m^3. For one storey, 3.6m high column , the maximum side dimension with a square section would be 15 - 19 cm.

It has been discussed before that the dimension of the column should not be too small so that load-bearing capacity of concrete can be brought into full play. From another point of view, the column can not be reduced indefinitely, because usually at least each corner of the column should have one longitude bars, the bars need a distance not less than 50mm (otherwise it would be inconvenient for the pouring of concrete)in between, and also that the covering concrete for the bar should be not less than 25mm[16], therefore, the smallest cross section of a column should be not less than 10x10 cmxcm. Actually, no column smaller than this has ever been found in SPCSS except the post-panel type which has smallest span between the post.

It should be clear that the smallest cross section is also confined by its slenderness ratio. However there are different stipulations for this ratio in different countries.

The following calculation is used to examine the load-bearing capacity of columns with a cross section of 10x10 cmxcm. The basic formula[17] is:

$$KN \leq \beta\ A(R_a + \mu R_a')$$

In the formula:

K -- factor of safety, K=1.55
N -- axial load of column
A -- cross section of column
R_a -- Max. allowable compressive stress of concrete
say R_a = 110kg/cm²
R_a' -- Max. allowable compressive stress of reinforcing
say R_a' = 2400kg/cm²
μ = A'/A A' is the total cross section of reinforcing
β -- Longitudinal bending coefficient

h/b	20	24	28	32
ß	0.75	0.65	0.56	0.48

h -- calculation height of column
b -- small side dimension of column

Say: h = 2.8m; A'= 2cm²
Then: h/b = 28; β = 0.56
A = 100 cmxcm
μ = 0.02

Therefore:

$N = \beta\ A(R_a + \mu R_a')/K$
$= 0.56 \times 100 \times (110 + 0.02 \times 2400) \div 1.55$
$= 5708$ kg

Suppose it is a one storey house, flat usable roof, and suppose:
live load = 200kg/m²;
dead load = 150kg/m²
then each column can support:
5708÷(200+150) = 16.3 m²

This means the grid of the column can be 4mx4m. This is bigger than many of SPCSS's grids. From here, it is evident that usually the column in SPCSS is big enough for load-bearing. It again demonstrates that it is not reasonable to reduce the grid to too small a size, except when the intention is to reduce the size of other components such as wall panels.

To reduce the weight of the column, the following methods were found to be used:

(a) The use of the precast hollow column, which can save considerable amount of material.

(b) The use of light weight concrete, which can reduce about 1/3 the weight of the components.

(c) The method of breaking the components into several pieces and/or combining precast and in-situ together: the precast part may be just the form mould, and then be cast on site into complete components at the same time with the casting of the joints; therefore the structure is more monolithic. The potential problem is that as the components in SPCSS are already small, the method will be hard to apply.

Fig.2.9
Column is divided into two pieces to facilitating manually handle
(JPM, 1979)

(4) Beam and floor/roof

There is nothing special to the design of beam in SPCSS. Its connection to columns and floor/roof components decides its shape. The beam usually takes the shape of a simple rectangle, "T" or "⊥". The "⊥" shaped beam can be partially prefabricated, and finished on site with the floor/roof components, to achieve integration between beam and floor members.

Sometimes, concrete beams can be replaced by other materials, such as timber, bamboo or steel trusses. Because the alternative materials are either more available or lighter to handle, lifting devices can be eliminated and on site work simplified.

The floor/roof component is an important part in a house using SPCSS in terms of structure and cost, but it is also an individual sub-system, which can be a special topic for study. Many of the systems have been developed for different conditions, functions and costs. The column-beam structure can produce a large range of variety by combining with those of the floor/roof systems.

For a sloped roof, usually no special design is necessary, and the conventional sloped roof components can be adopted directly. In some cases, when the slope is gentle, the roof can be made by adjusting the height of columns so that the beams may form a gradient by themselves, as in the case of the Apopa system.

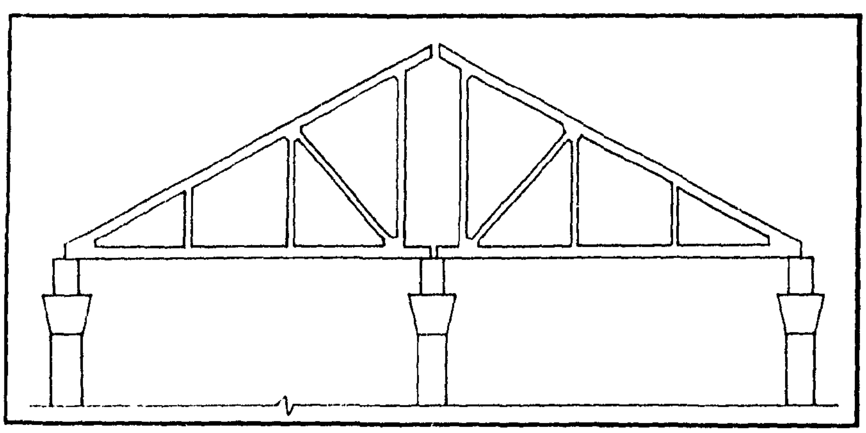


Fig.2.10 "NVEVOS HORIZONTES" developed in Argentina (After Sistemas, 42)

(4) Joints

Whether or not a SPCSS system is open or closed is largely dependent on the joints. This makes the joint design important.

Typical joints in SPCSS belong to two categories: wet joints, i.e., concrete in-situ joints, and dry joints, which include bolting joints, mortar joints, welding joints. Wet joints usually have a monolithic character, and they require a lower level of precision in construction, therefore easy to do for self-builders. But the construction process is time consuming for gaining necessary strength, and usually needing temporary propping.

Dry joints, by contrast, have the characteristic of fast construction. A structure with dry joints can be load-bearing immediately after assembling. But there also exist shortcomings with each type of dry joints. Bolting joints require a high level of accuracy in frame assembling; Welding joints are not suitable for many areas where welding machines are unavailable, and mortar joints are weak in strength.

2. PERFORMANCE ANALYSIS OF SPCSS

As a structural system, the skeleton seems attractive for low-cost housing mainly because of those features which are usually considered inherent in the skeleton. These are durability, earthquake and flood resistance, flexibility in choosing infill materials and architectural adaptability. The aim of this part is to examine these features one by one to test the accuracy of these assumptions and to have a better understanding of the performance of SPCSS.

2.1. Durability

Although in general, concrete structures have good durability, SPCSS is a special case, which makes its durability less certain. This is because the size of SPCSS's components are relatively small, especially the cover of reinforcement is thinner than the normal standards. For example, by the North American standard, the minimum thickness of the cover for the reinforcement is 1.5 - 2 in <3.81 - 5.08 cm>[18], but for SPCSS this thickness can be as thin as only 2.5 cm. Therefore, it is likely that the reinforcement in SPCSS will be rusted quicker than that in normal concrete structures, thus raising the question of the durability of SPCSS.

Strictly speaking, a discussion of durability of the concrete structure can hardly be made without a discussion of all the properties of its material, exposure conditions, structural design etc.[19]. That is to say, a definite durability is related to a specified system used in specific conditions.

The durability being understood here means that the designed life-cycle is long enough for its purpose[20]. Since the expected life for different kinds of buildings is not the same, there is no universal standard for durability. For housing, especially for low-cost housing, the expected life-span is around 50 years. This means a SPCSS could be regarded as durable if it could last about fifty years. For checking whether SPCSS is capable of lasting for this period of time, the best way is to review the houses already built. Works done on this aspect is scarce. Fortunately, in 1982-83, BRE (Building Research Establishment, England) made a fairly detailed inspection of the early built concrete houses in Britain, and among those, seven types of SPCSS houses were available for inspection.

Built between 1945-1950, the houses being investigated were set both in the countryside and cities. Their sites were a flat field, close to sea or hillside, and the houses were mostly 2-3 storeys for working class people. The concrete used was normal concrete except for one which used light-weight concrete (Woolaway). By the time they were inspected, most of the houses were already 30-35 years old. The seven SPCSS systems were: Unity, Airey, Woolaway, Parkinson, Orlit, Cornish Unit, and Ayrshire County Council(Lindsay) and Whitson-Fairhurst, and among these the Orlit, Airey and Woolaway are introduced in detail in the case study.

The action of inspection of the BRE included the following[21]:

(1) visual inspection of dwellings;

(2) visual inspection of structural reinforced concrete components;

(3) examination of components by taking samples of concrete for analysis of carbonation, chloride and cement contents, and by uncovering reinforcement for visual inspection of reinforcing and measurement of cover.

The main conclusions arrived at as a result of the inspection are: that the majority of SPCSS houses are in good or excellent condition; that some houses need to be regularly inspected and repaired; and that only a few Parkinson houses are reported to be un-repairable and were demolished. The conclusions are based on the following inspection results:

(1) most components were found to be under good condition and without cracking. Even when there was cracking the components had not lost their structural capacity.

(2) Even though in some houses, one or more components had lost their structural

capacity, these did not influence the stability of the whole structure. Besides, most of these damaged components could be replaced.

Through the investigation and analysis, it was found that the major factors caused the damage of components was carbonation. Carbonation does not directly cause severe corrosion of steel and cracking or spalling of cement cover, but it largely increases the risks when carbonated part exposed to wet conditions either indoor or outdoor[22].

The figures in the next page show the relationship between depth of concrete cover and depth of the carbonated part of the cover in the column in inspected houses. This demonstrates that for the majority of houses, the carbonation had not reached the reinforcement, but in many cases, it was very close.

The average depth of carbonation should be conservatively estimated to increase linearly with time; i.e., if half the depth of the cover has carbonated in 30 years, assume the remainder will carbonate in another 30 years. Having estimated the time for carbonation to reach the embedded steel it should then be assumed that corrosion and longitudinal cracking would commence immediately afterwards and that the column would became cracked throughout its length within 5 years[23].

According to the general results of the investigation -- that the carbonation in the majority of columns of SPCSS has not reached the reinforcement -- it is believed that all these houses could last at least another 5 years. This means their life-span is at least 35-40 years.

From the study some inferences can be made: since these houses being investigated, with the concrete cover of reinforcement of 2-2.5 cm, have a life span of 35-40 years, then most SPCSS houses built later, with concrete cover for

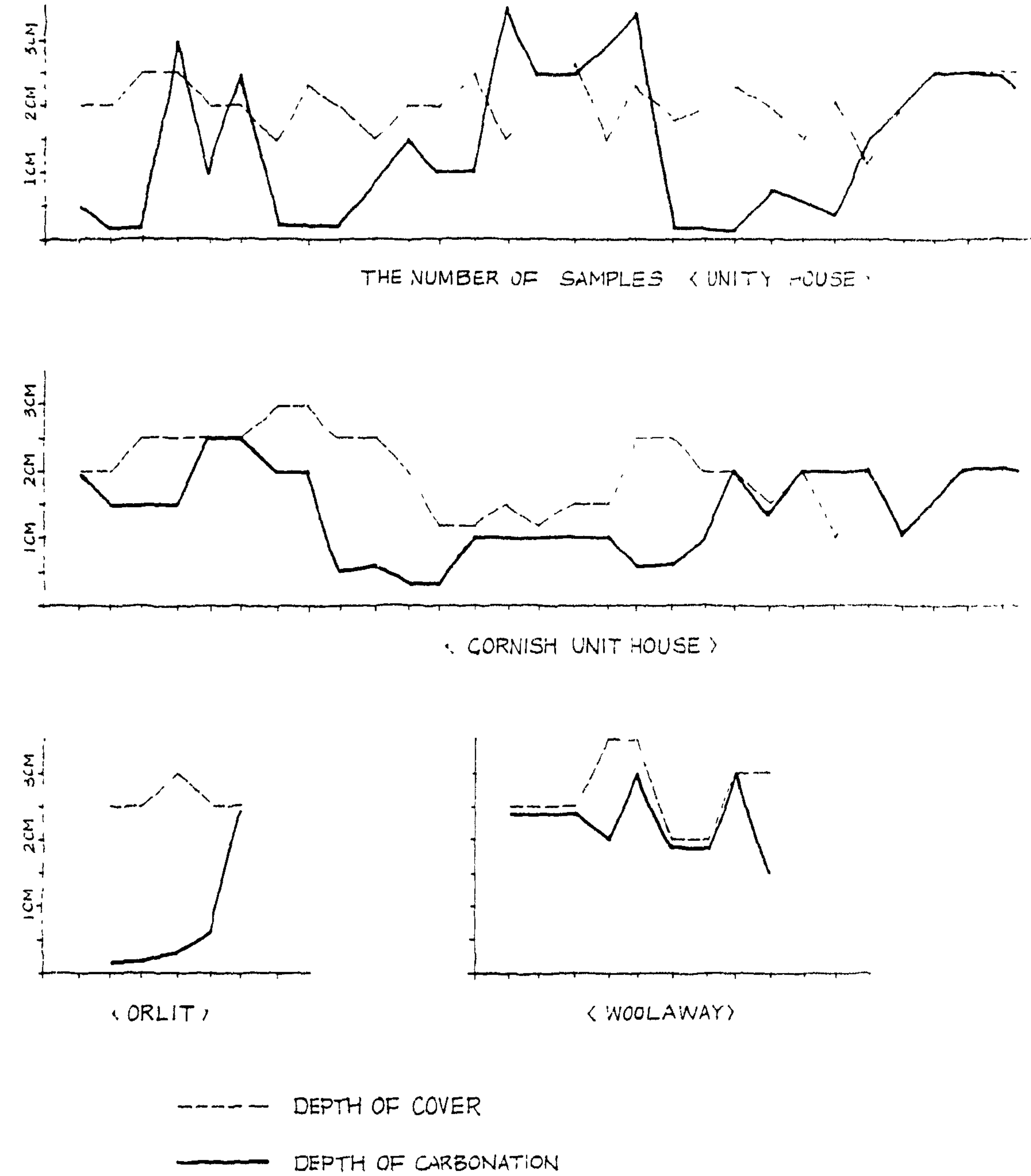


Fig.2.11 Cover of reinforcing and carbonated depth in the cover of the columns in early British systems

reinforcement of minimum 2.5 cm, averaging 2.5-3 cm, should have a life-span of at least 42-50 years. Considering the estimation is relatively conservative, it is conceivable that SPCSS is durable for its purpose as a housing structure.

The suggestion is: for the areas where there is a humid environment similar to England, it is safer to adopt a concrete cover for reinforcement of over 3 cm. This would still be suitable for SPCSS in terms of its property of the small component as discussed in the design study.

In BRE reports, there are several other points which are worth mentioning .

(1) Most reports pointed out that there was more cracking found on the lower part of the columns on the ground floor, because the humid environment accelerated the corrosion of reinforcement. This finding suggests the use of relevant treatments on columns. For example, concrete cover should be thicker on the bottom of the column or a coat of protective material should be applied. This part should also be regularly checked or repaired.

(2) When columns and beams were connected by bolts, the bolts were likely to corrode first. A typical example is the Parkinson house[24]. Significant cracking and disruption in the joints between beams and columns caused the instability of these houses. Therefore, this type of joint needs to be examined regularly.

(3) For the SPCSS with the "small span" columns, unless several neighboring columns crack simultaneously, a few damaged components would not influence the whole structure and the damaged components could be repaired or replaced.

(4) The overall stability of houses is not always dependent on the condition of the reinforced concrete frame, but, in most cases, also depends on the infill walls and the connection between wall and skeleton.

2.2 Resistance to Climatic Stress

(1) Anti-seismic/wind Structure

Normally the skeleton is a good structure for resisting earthquake damage, but for SPCSS, this is questionable mainly due to the loss of continuity in connections of structural components. For seismic resistance, the joints of SPCSS should be specially designed. Also, it should be noted that with the requirement for seismic resistance, the structural components will be bigger and heavier, and the joints may be complicated, which may add problems in construction.

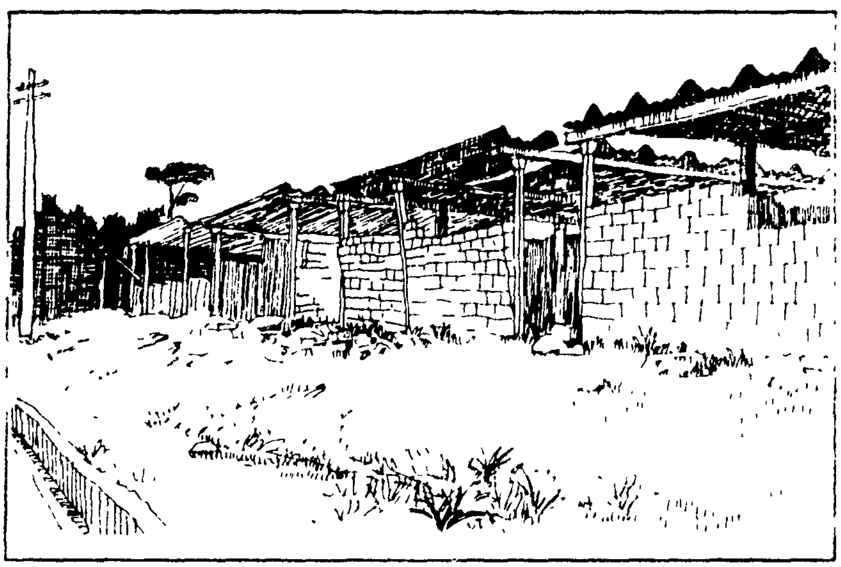


Fig.2.12 Skeleton house in Managua after earthquake (Managua, 86)

Besides, in order that the whole building and not only the skeleton part, be resistant to earthquake, the design and construction of the infill parts should also be considered carefully. Fig.2.12 shows a skeleton house in Managua. Because the wall and the skeleton were inadequately anchored, the wall collapsed in an earthquake.

When SPCSS are used in extremely low-cost housing, the walls might adopt any kind of available materials as in-fill. In this situation, the anti-seismic capacity of housing is usually conceived of such that even if the walls collapse in an earthquake, the frame structure and the roof will remain. Thus the rebuilding task would be much easier.

Therefore it can be stated that SPCSS is only one of several good alternatives for an anti-seismic structure, but anti-seismic is not its inherent feature. Special considerations are needed in the design for this anti-seismic capacity.

For wind resistant, the performance principle is similar to earthquake resistant, therefore, they have the similar results.

(2) Resistance to Flood

In flood prone areas, traditional housing has adopted the timber frame to resist flood for thousands of years. This type of housing is often built on stilts. Now, timber has become scarce, therefore the strong, durable, and waterproof quality of concrete structure makes SPCSS a natural choice to replace the timber frame for anti-flood houses. Among the cases reviewed, the Xinti and Grameen systems were designed intentionally to resist flood. For the Grameen system, the houses were built on a high platform to protect against the flood; even when the flood level rises over the platform, the concrete columns in the four corners can keep the bamboo matting wall houses standing. After the flood, if the land is eroded, the columns can be easily taken out and moved to a higher place to rebuild the houses. For Xinti houses, it was assumed that when the flood came, people could move to the second floor. The walls on the first floor might be destroyed, but they would be easy to replace without changing the basic structure and during the reconstruction as well as the flood period, people would not be rendered homeless.

As is mentioned earlier, the lower part of a column gets cracked easily, especially in the damp condition caused by frequent flooding. For this reason, the bottom part of column for flood resistant houses should be specially treated. However, this is not found in most cases, the intention may be to keep manufacturing simple.

Except for the methods mentioned in section 2.1 of this chapter, for the treatment of bottom part of column, the design of the Orlit system, with the column embedded in the foundation and separated from the upper part, is another alternative for the flood resistant house. In this way, the column in lower part can be bigger and have a thicker cover for reinforcement.

2.3 Flexibility / Restriction in Choice of Infill Material

Since the walls in the skeleton system are not load-bearing, theoretically, they can be made of any kind of material. Therefore, in places where the material for the load-bearing wall -- mainly burnt brick -- are scarce or poor in quality, SPCSS would be a suitable structure.

This property of SPCSS leads to another popular assumption: that the construction price can be reduced by using the locally cheapest materials and that houses can be upgraded in the future with economic growth.

There were successful applications of this idea. For example, the Grameen houses, in which the SPCSS components were used just to reinforce the structure of the conventional low-cost houses, the traditional bamboo matting wall was retained.

But there may be problems in some situations. Users sometimes do not like the idea of using cheap infill wall to maintain cost low. They would often rather use a relatively moderate solution, which is cheaper than the concrete structure but looks and performs better than the cheapest in-fill materials.

A typical example is the project done in Panama, which we have already mentioned in the history review. This was initially a plan designed to be able to expand in a town called Los Positos. Later, it was developed in 19 other villages in Panama with the help from the U.S. Foundation for Cooperative Housing. In this project, for each family, a skeleton together with a service core was provided. They were completed by self-help and could be expanded in the future. The architects involved -- both foreign experts and local architects -- expected people to use traditional cane as wall material. As reported by Charles Dean, the architects " were attracted to the cane because it is romantic and it looks better -- everybody thinks concrete block is ugly. But the people living there wanted concrete block because all the houses in town were concrete block[25]"

Eighteen sq m core house includes toilet and shower and one room to be expanded and completed by self help Panama

Fig.2.13 People prefer concrete block for in-fill wall in Panama project **(Dean,87)**

For the purpose of rapid construction, expensive material may be chosen for the in-fill wall like in the post-panel system. This system was reported to be the most expensive one in some areas[26]. But it was a relative success. On close examination, it shows that this kind of system was used always in subsidized conditions, such as in the post-war period of England, Cuba and other socialist countries.

Thus, it can be inferred that in different situations, cost is not the only measure of success in the choice of in-fill material.

2.4 Architectural Adaptability of SPCSS

The "Pessac housing project" designed by Corbusier has been changed dramatically by its users. From the adaptability point of view, the changes made to the Pessac confirmed the inherent flexibility of the skeleton system, that allows users to rearrange and reorganize their houses according to their own needs.

The flexibility of a building can be judged mainly from the following aspects:

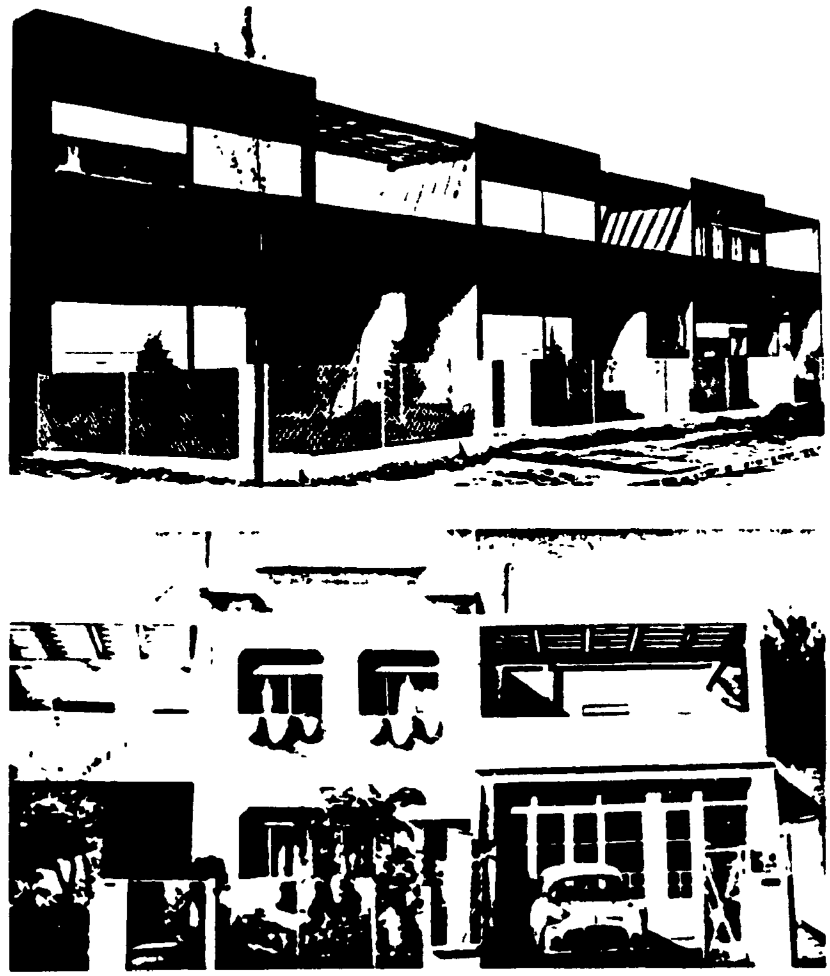
--- Flexibility in Dividing Interior Space

--- Flexibility in Extending the Building

--- Flexibility in Form and Style

--- Flexibility in the Application of the System

Fig.2.14 Pessac, 1925-1969
The use of skeleton has allowed for many changes in use and construction (Jencks, 75)



(1) Flexibility in Dividing Interior Space

Theoretically, the wall in SPCSS houses can be moved anywhere at any time, because it is non-load-bearing. Actually, this is only absolute for the first floor. For the upper floors, however, the flexibility is limited.

The restraints come from two aspects, except the restriction of design as in post-panel system and the system in Fig.2.15 which flexibility is even less. The first aspect is the wall material. For many developing areas the light materials are not readily available. When heavy materials such as burnt brick are used, their layout has to be restricted by the layout of the beams. The second aspect is the placement of the staircase, because the staircase usually determines the entrance and the main circulation area. Very often when the staircase in a building is fixed, there appear to be only a few options for change of interior layout (fig. 2.16).

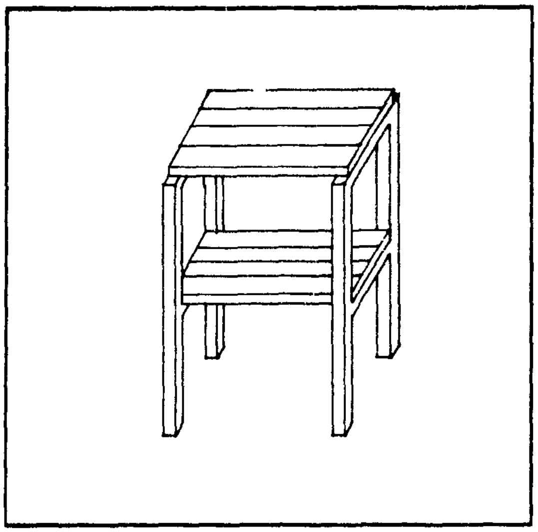


Fig. 2.15

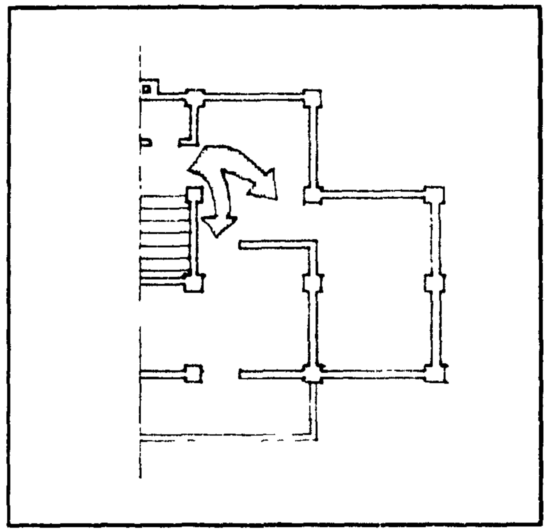


Fig.2.16

(2) Flexibility in Extending the Building

Cases have shown that the skeleton is not inherently extendable. That is to say, if a SPCSS house needs to be extended, it is hard to use the original system in the new part, unless a special design has already been made for the skeleton, as in the case of the Mitchell frame. The problem is that the new skeleton can not link easily with the old ones. When the house is to be extended vertically, there is another problem of load-bearing capacity of the original system. In the Mitchell frame, the load-bearing capacity of the columns on the first floor are the same as those on the fourth floor.

This overload design would unavoidably waste some material. Therefore, for SPCSS, the extension is mainly done in horizontal directions.

In combination with other systems, extension is easier for the SPCSS house. Since the walls in many SPCSS systems are portable, the old house can be totally rearranged to blend with the new one, no matter what kind of structure is to be used in the new part. This is good for the house which is prepared for future extension

Fig.2.17 Skeleton used in Site and Service project in Nicaragua (Proyecto, 30E)

(3) Flexibility in Form and Style

For the SPCSS house the arrangement of non-structural elements on elevated parts -- the placing of windows, decorations, etc. -- is usually free, but the overall shape of the house is rather restricted due to the limited size and number of skeleton components.

(4) Flexibility in Application of the System

There are two aspects to the flexibility in application. One is that the system can be used for different buildings. Usually the bigger the structural span, the more flexibility it has. For SPCSS, the span tends to be small, and this is its drawback for application.

The other aspect is that the system should be open or closed. From the existing cases, it is clear that the majority of the SPCSS systems are closed, i.e. the components usually can not be used separately with components in other systems. The more complicated the system, the more closed it is. For low-cost housing, this means for many situation the SPCSS is hard to be adopted. For example, many people reuse the old materials and just buy some new parts to build their new houses. SPCSS would not be flexible enough to satisfy their requirements.

In conclusion, flexibility of SPCSS means (1) the layout of each floor is independent, with the first floor having unlimited flexibility (except the system in Fig.2.15 and the post-panel system) and upper floor flexibility dependent on materials and housing design; (2) the SPCSS house usually can be extended easily but not the SPCSS itself; (3) SPCSS does not provide flexibility for the overall shape of the house, but it provides the freedom for openings and detail constructions; (4) SPCSS is limited to buildings of small spans, and its component system is normally a closed system.

Actually, the majority of houses do not need un-limited flexibility. Although SPCSS performs best in a well-defined finite situation, the degree of flexibility is usually adequate for housing needs.

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PART TWO
CASE STUDIES

The main body of this part is devoted to a detailed survey and analysis of SPCSS. It is based on an exhaustive examination of literature from every available source ---- libraries, interlibrary loans, and direct contact with the designers and related institutes. In spite of long development history and wide spread to different countries, majority of the systems have not been effectively documented. The structural design data is especially difficult to obtain. This makes the comparison between different systems more difficult. Among the 41 systems found, 15 systems* have been selected here for presentation. The selection of systems is based on one or more of the following factors: the most important being that sufficient information be available for each system in terms of system design, prototypes and the design consideration in manufacture, transportation, construction, architectural features and applicational flexibility. There are many systems with similar design and enough information, but only a typical one has been chosen. Some systems may be not typical but have been widely used or have some interesting design ideas, therefore they will also be presented.

The systems are classified into two major groups: one story structure and multi-story structure. The reason for this classification is that the height of the structure is the most important factor affecting the design and construction of a system. In each group, the cases are systematically arranged from simple to complicated in terms of manufacture and assembling.

Another potential classification is according to the specified structural performance of the cases, such as earthquake-resistant, fast erection, etc.. But this is more difficult, because some cases have more than one major feature; some may not have any but can easily accommodate them.

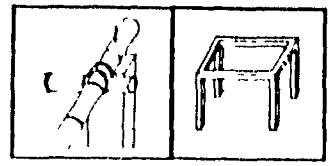
* The sources for the rest of 26 systems are attached at the end of Case Studies

In order to get the basic information easily, a brief description of each system --- its source, structural type, name, status of system and specified function --- will be provided in the beginning of each case.

The following systems are evaluated:

	Name of System	Functional Classification
No.	For single story SPCSS:	
1.	Grameen System	Flood-resistant, fast-erection
2.	Shan Xi System	Earthquake-resistant, fast-erection
3.	Apopa System	Earthquake-resistant
4.	Singh System	Earthquake-resistant, general use
5.	Gupta System	Earthquake-resistant, fast-erection
	For two or over two story SPCSS:	
6.	Hanchuan System	Flood, earthquake resistant, fast erection
7.	Anju System	Earthquake-resistant
8.	Xinti System	Flood-resistant, fast erection
9.	Barcares-leuate System	Fast erection, free expansion
10.	Match Stick System	Earthquake-resistant
11.	Mitchell Frame System	Fast erection, free expansion
12.	MIT System	General use, earthquake-resistant
13.	Orlit System	General use, flood-resistant
14.	Airey System	General use
15.	Woolaway System	General use

SYSTEM'S NAME: Grameen System[1]



DEVELOPER: Grameen Bank, Dhaka

STATUS: Since 1984 to 1990, 59,000 houses have been built over Bangladesh

SUB-CLASSIFICATION: Flood-resistant, fast-erection

---

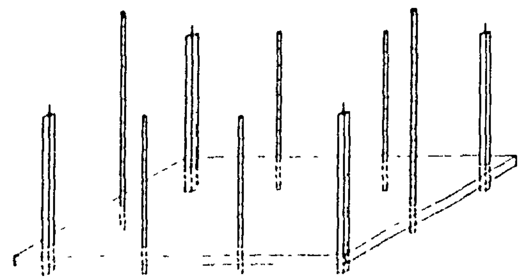
1. Introduction

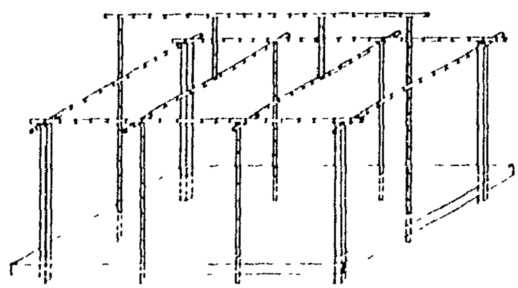
The Grameen system was developed for the Grameen Bank Housing Project. This housing project was a part of Grameen Bank program which was started in 1976 to raise the income and the standard of living of the most disadvantaged sector of the rural community in Bangladesh by providing access to credit The houses are built with loans; its aim is not only to achieve a basic, durable, and flood-resistant structure, but also to suit local context and available resources The typical family shelters in much of Bangladesh are made of bamboo and reed mats simply laid against a makeshift frame and without foundations. They are precarious dwellings, particularly vulnerable to high winds and flooding during monsoons. The new houses are covered by corrugated iron sheets, supported by four concrete columns manufactured by the Bank, and the walls still use the same material as in traditional houses. The floors are raised above ground level to prevent flooding. The structure was designed so that in the event of serious land erosion, the columns can be lifted out allowing for the whole house to be moved to higher, safer land This system has no technical innovation, but it provides affordable improvements to traditional shelter.

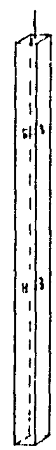
This project won the Aga Khan Architectural Award 1989.

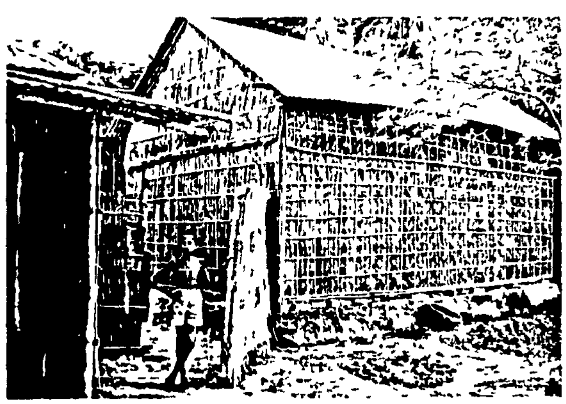
2. Description of System

The system just uses concrete in column to reduce the cost, the beam use bamboo as alternative. This is not only cheap but also easy in assembling the frame.







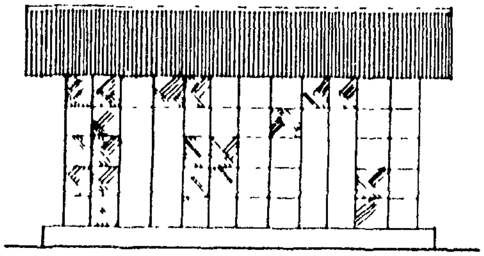


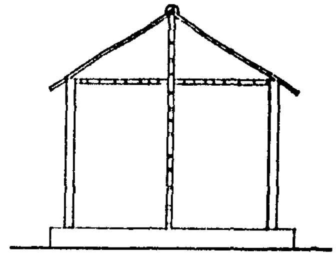
3. The Evaluation from Design Consideration

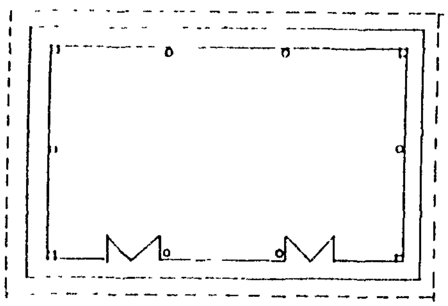
Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are very simple in making
	Mechanical device	Not required
Transportation		No problem in transportation
Construction	Kinds of components	There is only one concrete components in the system
	Weight	Components are light
	Equipment	No equipment is needed by user
	Speed	Fast in assembling
	Special requirement	There is no special requirement
Architectural feature	Interior flexibility	Very flexible in interior layout
	Extension	System can be extended easily
Flexibility in application		Total inter-changeable

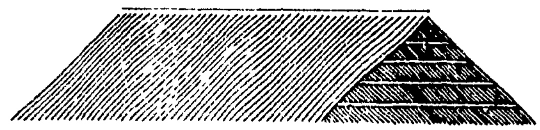
4. Prototype of Project

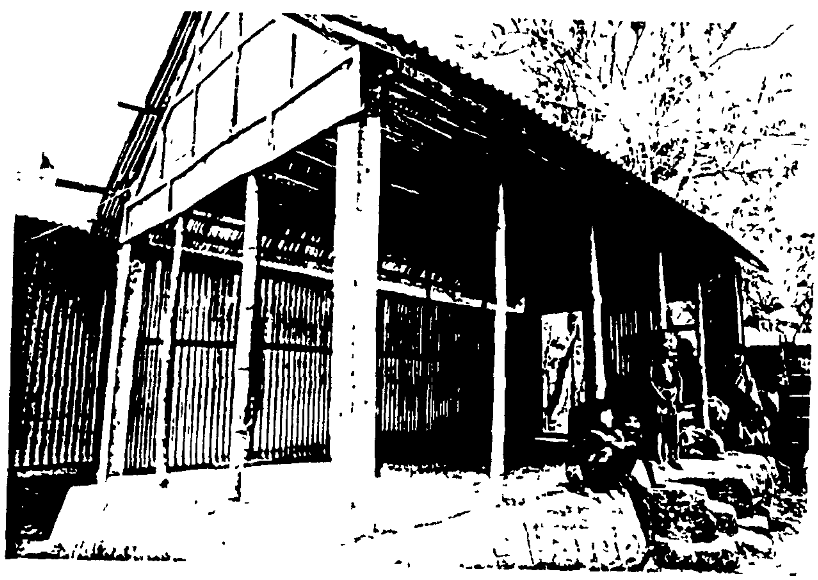
The basic house plan is 20 square meters. It has four concrete columns with additional posts of wood, bamboo or concrete. Individual houses are built by users who choose the layouts and the infill wall materials. Therefore, no two Grameen houses look the same.



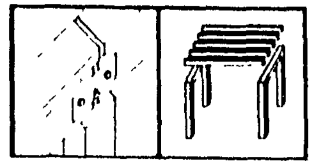








SYSTEM'S NAME: Shan Xi[2]



DESIGNER OR DEVELOPER: Dong Hong Zhi

STATUS: No reported utilization
Designed in 1984, Shan Xi, China

SUB-CLASSIFICATION: Earth-quake resistant, fast-erection

---

1. Introduction

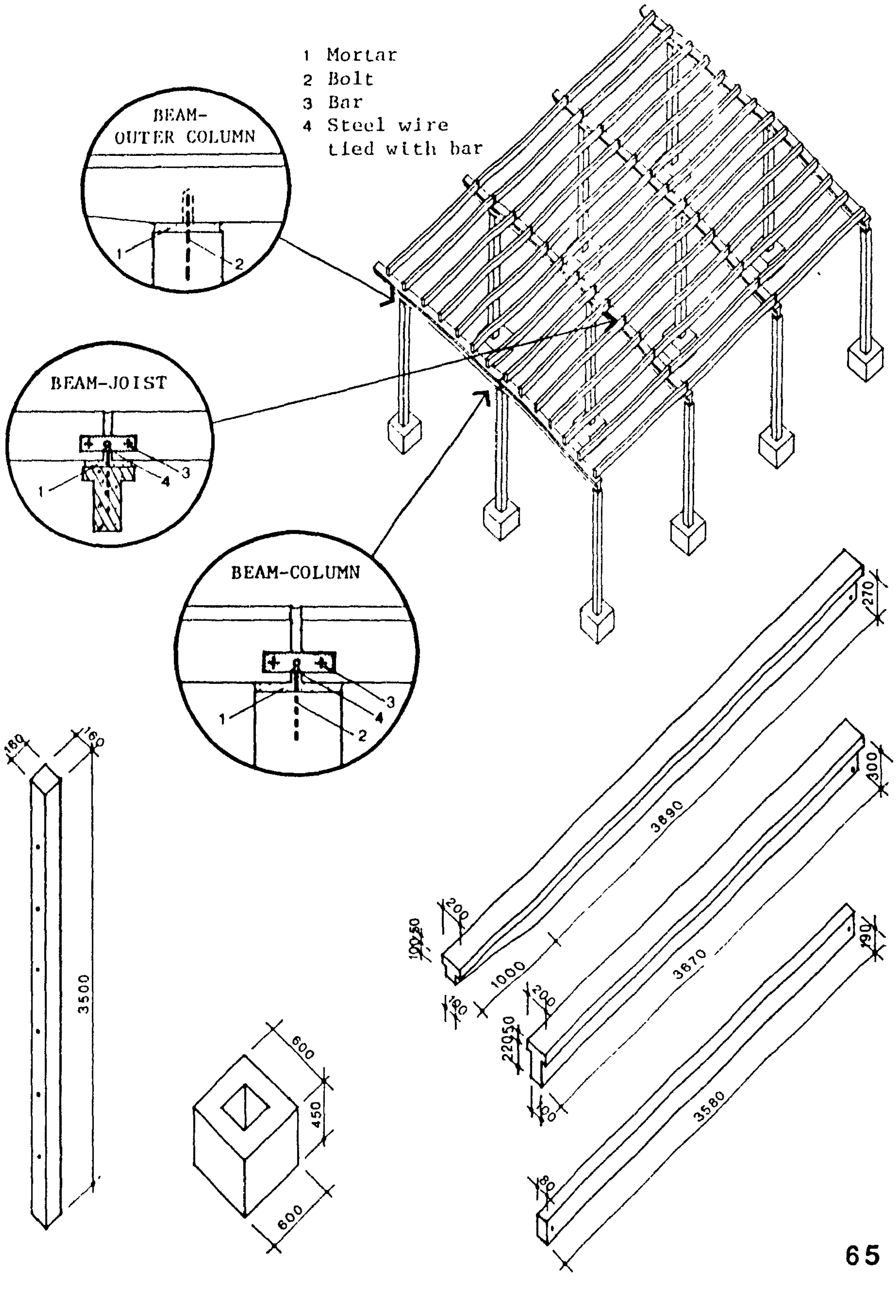
This system was developed for the Shanxi rural houses, which, traditionally, were mainly one storey adobe wall structure. Many of them were to be rebuilt at the time that the system was developed.

Shanxi being a seismic area, the rebuilt houses need to adopt anti seismic structure. At the time, a structure using load-bearing brick wall and reinforced concrete joist roof with special anti-seismic treatment had already begun to be used in rural housing.

Applying the policy to use concrete components to replace conventional burnt brick, this system uses a concrete skeleton, which has better anti-seismic performance than load-bearing wall structure.

This system is an open one, i e. components in the system can be used by combining with the other systems The components in this system are also relatively simple, and they can be made by un-skilled labour. The major characteristic of the system is its joint design, which has two advantages. One is that it is very simple and does not require high accuracy for erection, the other is that it can be load bearing immediately after assembling.

2. Description of System

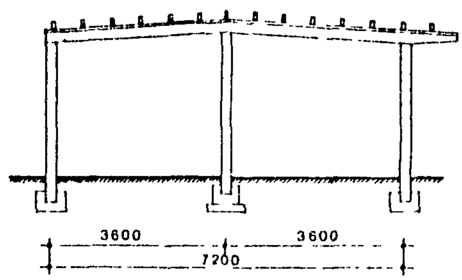


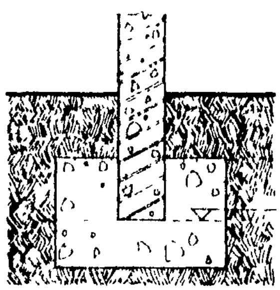
3. The Evaluation from Design Consideration

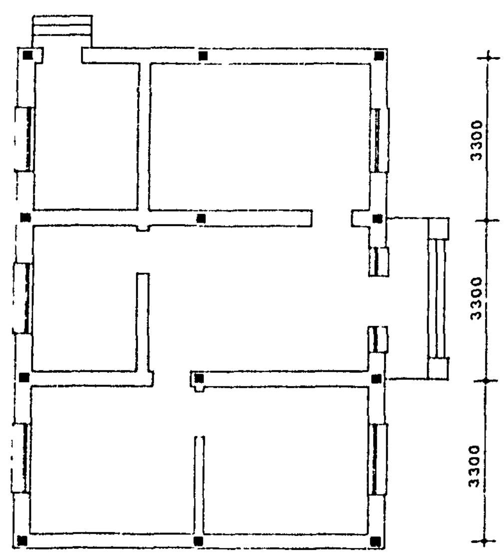
Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are very simple in making
	Mechanical device	The beam in the system is too heavy to be manually handled, simple lifting device is needed.
Transportation		No problem in transportation
Construction	Kind of component	There are four kinds of components in the system
	Weight	Components are too heavy to be manually handled
	Equipment	Simple lifting device is needed
	Speed	Fast in assembling, load bearing immediately after assembling
	Special requirement	There is no special requirement
Architectural feature	Interior flexibility	Very flexible in interior layout
	Extension	System can be extended in one direction
Flexibility in application		System is totally inter-changeable

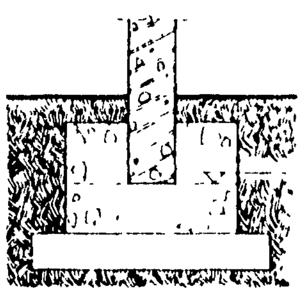
4. Prototype of Project

In the prototype project, the bottom of the wall was constructed with burnt bricks, the upper part was adobe. The wall should be connected with the bars pre-embedded in the columns for monolithicity.







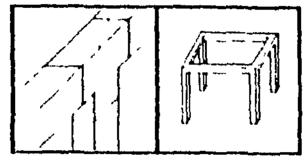


SYSTEM'S NAME: APOPA[3]

DESIGNER OR DEVELOPER: I.G. Lippsmeier,

STATUS: Prototype project was built in El Salvador, 1970's

SUB-CLASSIFICATION: Earthquake resistant



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1. Introduction

During the 1970's, El Salvador government was resettling the slum inhabitants by self-help housing. One problem in the resettlement process was that the poor inhabitants, who came mainly from rural areas, could not afford the prevailing construction methods used in the city for their houses. Traditionally, the people in rural areas used adobe building methods, but this method had many disadvantages, such as collapse in earthquakes and short life-cycle. To solve these problems, a research program on low-cost housing construction was carried out. The Apopa system was one of its achievements

The main features of the design of Apopa system are:

(a) Resistance to earthquakes and windstorms.

(b) Suitable for self help programmes.

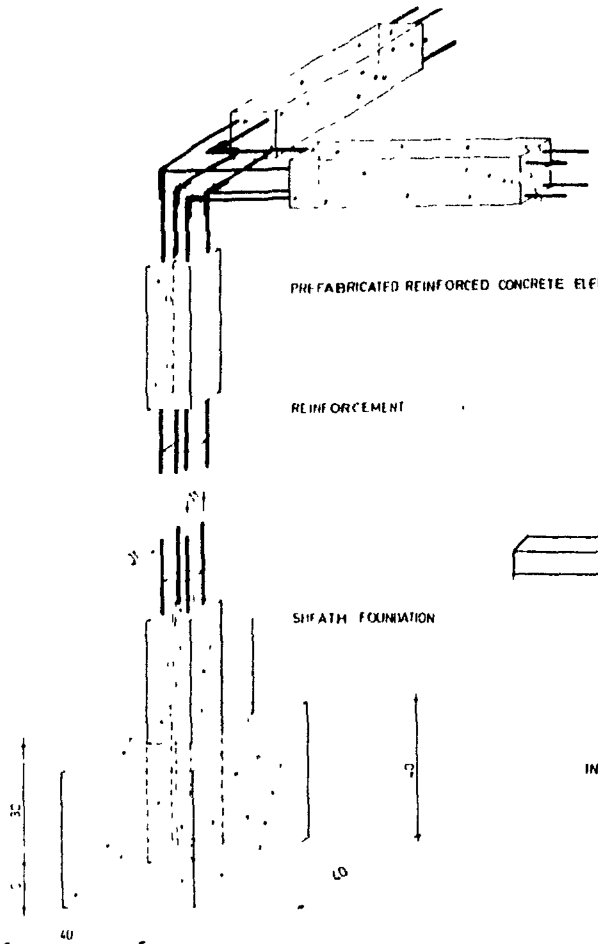
(c) Lower costs than the prevailing methods.

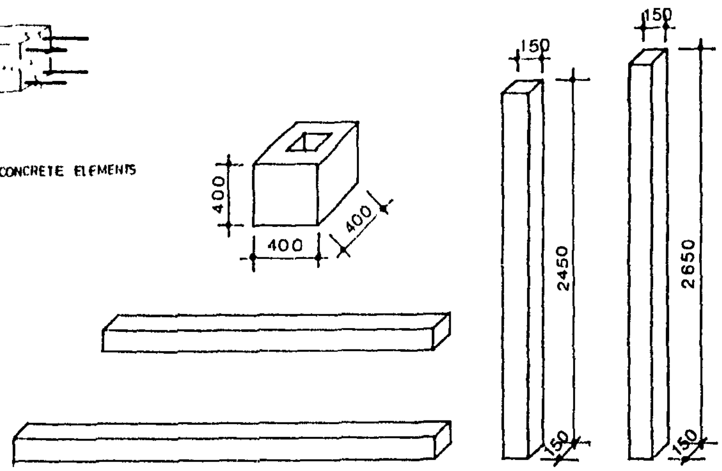
(d) Use of local materials.

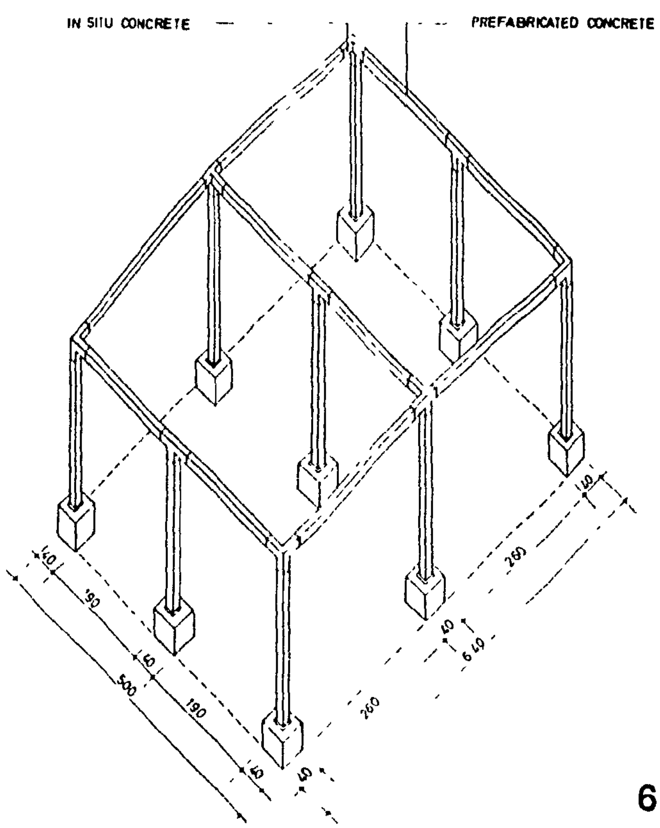
(e) Adaptable to the existing building style, there should be no radical changes.

(f) Easy to maintain.

2. Description of System







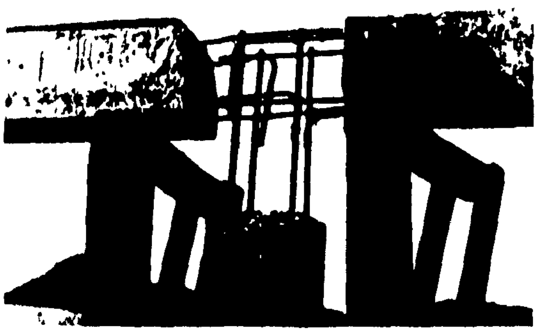
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are simple and light enough to be manually made and handled
	Mechanical device	Not required
Transportation		Components are easy to be transported with simple vehicle
Construction	Kinds of components	There are five kinds of components in the system
	Weight	Components are light enough to be manually handled.
	Equipment	For the convenience, a simple lifting device was developed for the system.
	Speed	The construction process is simple and quick, but curing process of the in-situ joints take time
	Special requirement	No special requirement
Architectural feature	Interior flexibility	Interior flexibility is very good
	Extension	System itself can not be extended
Flexibility in application		System is totally inter-changeable

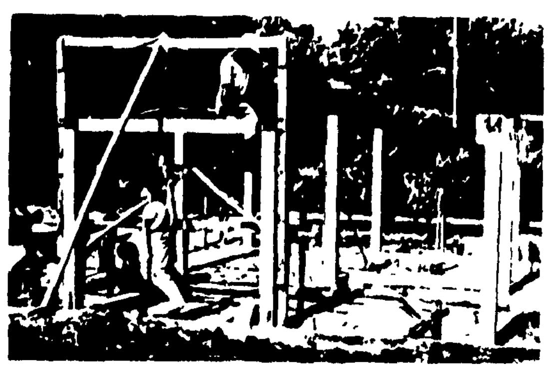
4. Prototype Project

The prototype project is a single story house. The roof is of asbestos cement corrugated sheeting which is fastened to the beams with aluminum wire hooks. The wall is filled by adobe bricks.

SKELETON HOUSE IN APOPA



DETAIL OF ELEMENT CONNECTION



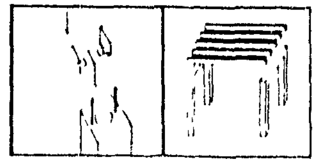
LIFTING THE SKELETON COMPONENTS

SYSTEMS NAME: SINGH[4]

DESIGNER OR DEVELOPER: C.B.R.I*., India

STATUS: Prototype was built in 1976

SUB-CLASSIFICATION: General use & earthquake-resistant



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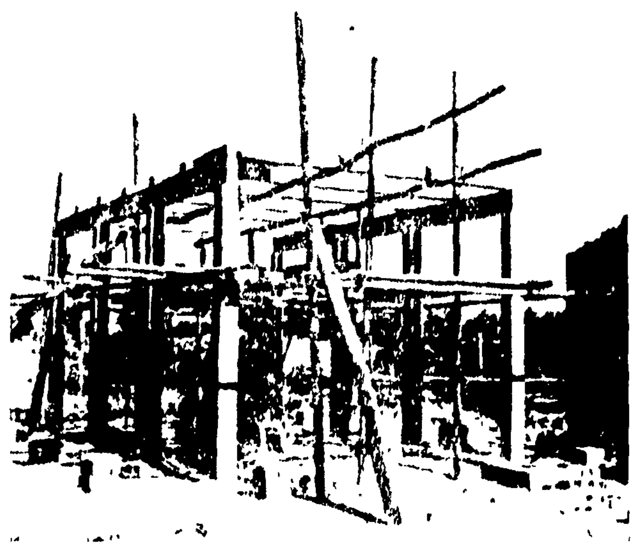
1. Introduction

The Singh system is designed for one story houses in rural areas, where the quality of bricks is very poor. It is used to replace the poor quality load bearing wall

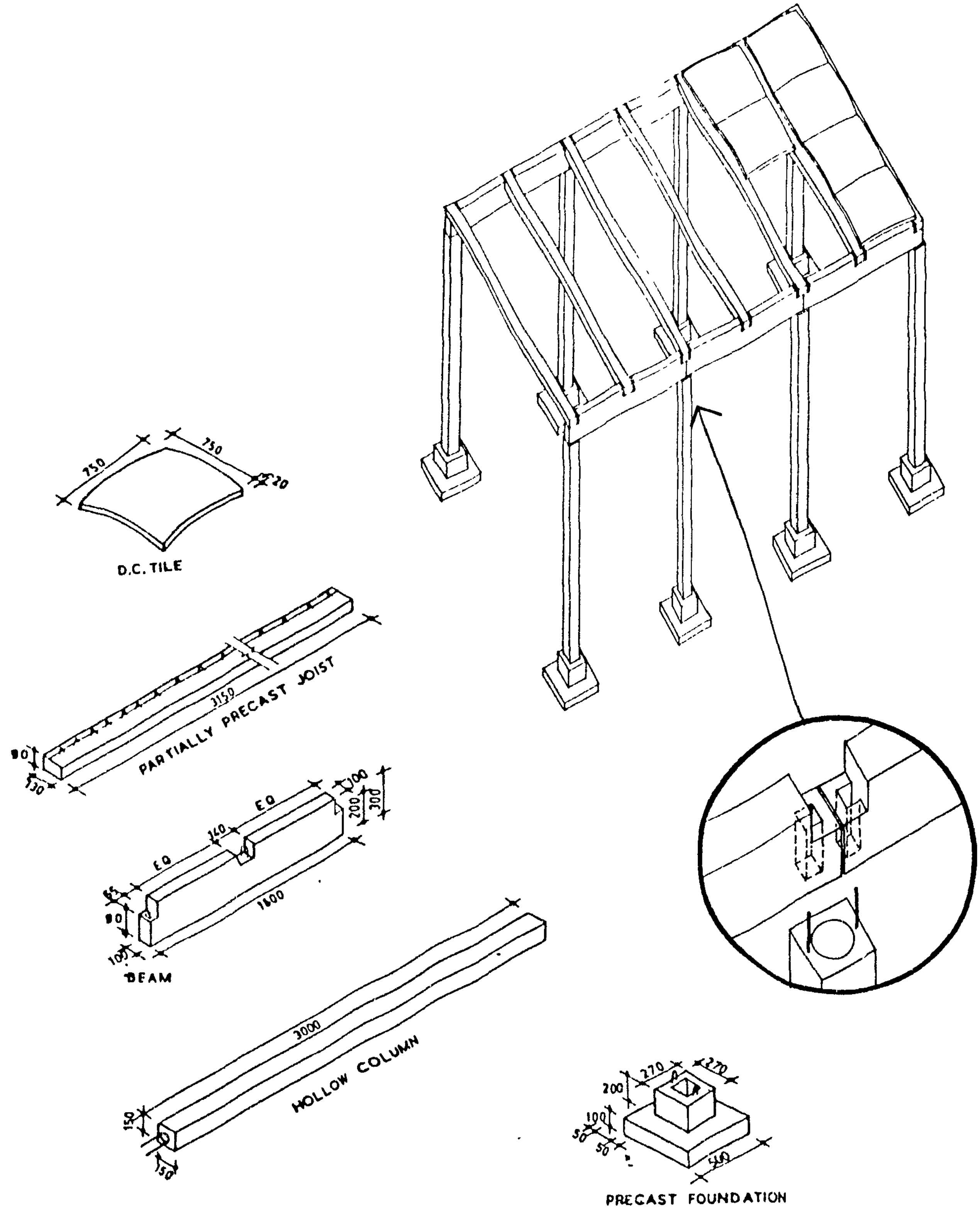
The design of this system is based on the concept that the house construction is finished by stages. The first stage is erecting the skeleton as the support structure, followed by the construction of walls, doors and windows with locally available materials Four methods are used to reduce the weight of components: small space between columns in lengthwise; partially prefabricated joists in crosswise; hollow columns and curved tile.

Studies show that the system can be applied to seismic areas by modifying the section design of column After the modification, the heaviest component, i e the column is still only about 245kg and can be handled by three persons manually.



* C.B R.I: Central Building Research Institute

2. Description of System

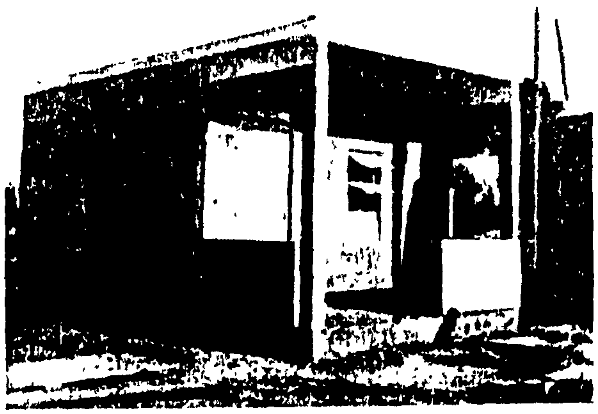


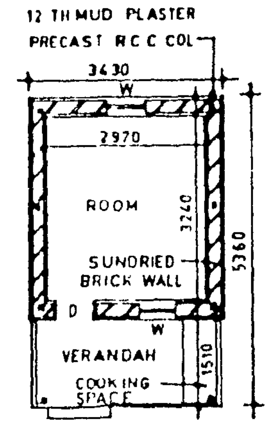
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are simple and light enough, they can be manually made and handled
	Mechanical device	Not required
Transportation		Care should be taken in transporting the partially precast beams in case of cracking, especially under poor transportation conditions
Construction	Kinds of components	There are five kinds of components in the system
	Weight	Components are light enough for manual handlers
	Equipment	No equipment is needed.
	Speed	The speed is low because the joists need to be propped up at every 1m intervals until the concrete in the haunch has attained sufficient strength It takes about two weeks
	Special requirement	When building the roof, worker should not walk on the tile and have to arrange proper "cat walks."
Architectural feature	Interior flexibility	Interior flexibility is very good
	Extension	System itself can not be extended
Flexibility in application		System is not inter-changeable

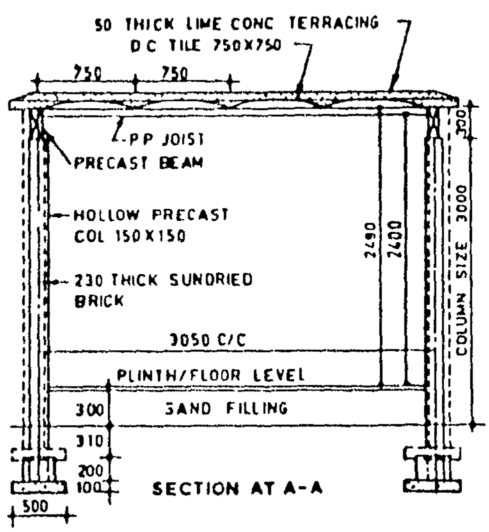
4. Prototype Project

The prototype project is a single story rural house. In this project, all the masonry work up to plinth level is done with burnt bricks in 1 6 cement mortar. Flooring is clay flooring tiles laid in cement mortar and doors and windows are frameless with local wood shutters. The roof is finished with lime concrete terracing laid on curved tiles to the required slope

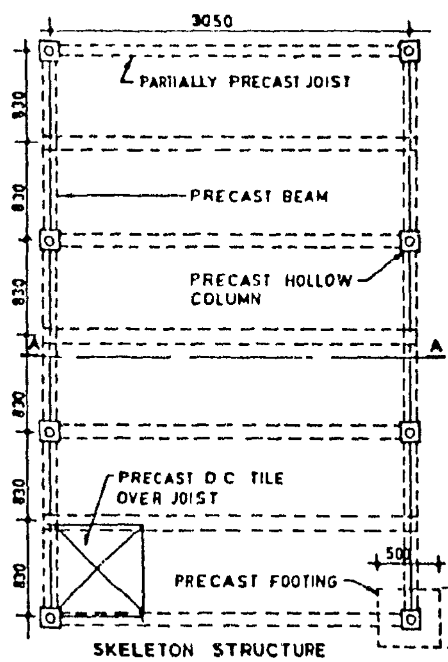




PLAN

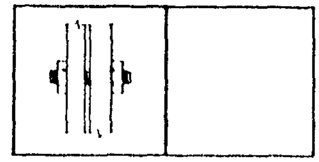


SECTION AT A-A



SKELETON STRUCTURE

SYSTEMS NAME: GUPTA[5]



DESIGNER OR DEVELOPER: C.B.R.I. INDIA

STATUS: Prototype was built in 1980's

SUB-CLASSIFICATION: Earth-quake resistant & fast erection

1. Introduction

Many structural systems and techniques were developed for construction of low-cost houses in C B.R I But special consideration was needed while constructing in seismic regions. The most common structural system for houses in those regions are load bearing wall of stone, burnt or sundried brick masonry supported over strip foundation. These systems are quite vulnerable to occasional but significant lateral force developed in seismic region With advancement in technology and increasing demand of housing it was necessary to develop a durable, functional and economical structural system for low-cost houses partly based on industrialization.

Designed for quickly erected low-cost housing, the Gupta system was cheaper than locally used 23cm brick load bearing wall and 10cm R C C Slab structure, and there was possibility of employing local material for self-help housing

In order to increase the monolithicity to resistant earthquake, this system uses frame panel in stead of post and beam The employment of frame panel reduce the section of structural components and the consumption of material.

2. Description of System

1 Deck Reinforced Concrete

2 R.C.C.Solid Planks

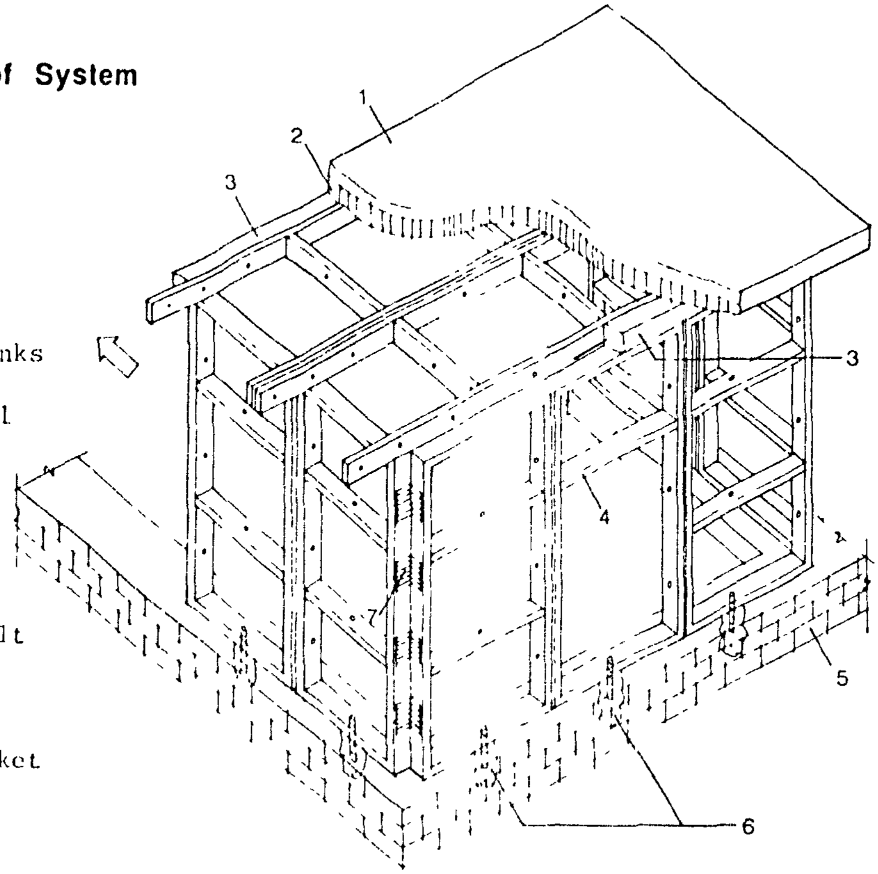
3 R.C.C.Peripheral Beam

4 Door Frame

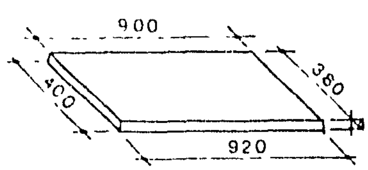
5 Foundation

6 Holding Down Bolt Embedded in Concrete

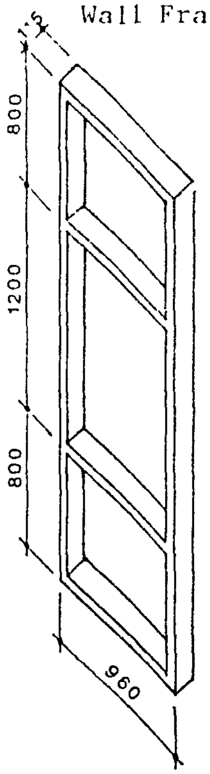
7 M.S.Corner Bracket



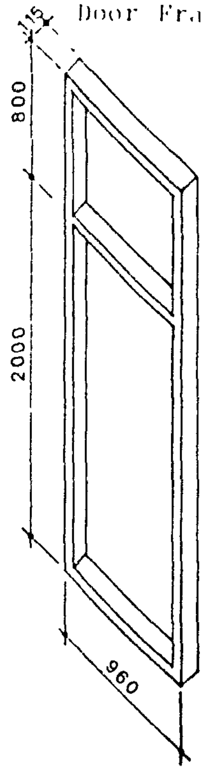
R.C.C.Solid Plank



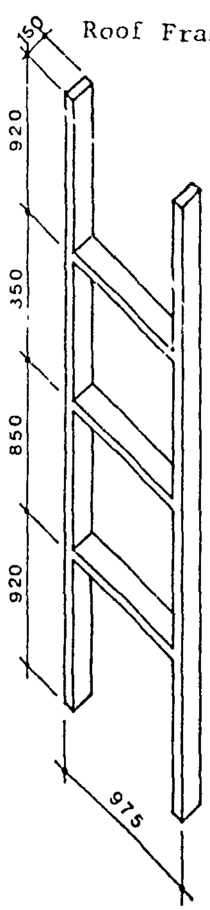
Wall Frame



Door Frame



Roof Frame



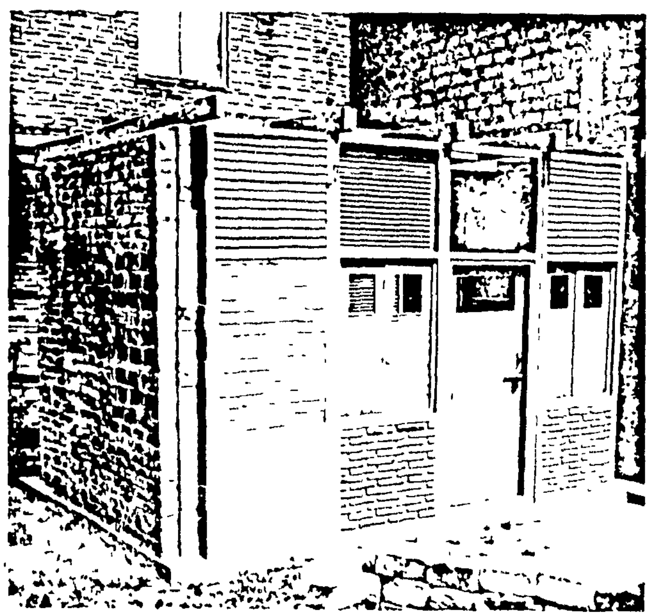
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are simple and light enough, they can be manually made and handled, but due to the small section of the frame, good supervision in manufacture is needed to control the quality.
	Mechanical device	
Transportation		There is no difficulty in transportation
Construction	Kinds of components	There are four kinds of components in the system
	Weight	Components are light
	Equipment	No equipment is needed.
	Speed	The construction speed is high
	Special requirement	No special requirement
Architectural feature	Interior flexibility	Interior flexibility is limited by existing wall frame.
	Extension	System it self can not be extended
Flexibility in Application		System can use different roof components

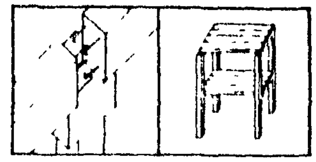
4. Prototype Project

The prototype is a single room 4x3 m in plan. Its foundation is a brick masonry strip The wall frames are erected side by side over it. Bolting connections are used to hold the wall frame and roof frame together. The vertical joints between two wall frame is grouted with cement mortar. Water sealant material sheet or manila rope dipped in bitumen is used between two frames on the outside so as to make the joints water tight. The wall infill material used bamboo, wooden grills, sundry bricks and burnt bricks.

The actual house could only expanded in longitudinal direction, the perpendicular direction was fixed in 3m span by the system design



SYSTEM'S NAME: HANCHUAN[6]



DESIGNER AND DEVELOPER:

STATUS: Five Prototypes were built in 1982, Hanchuan, Hubei, China

SUB-CLASSIFICATION: Flood and earthquake resistant & fast erection

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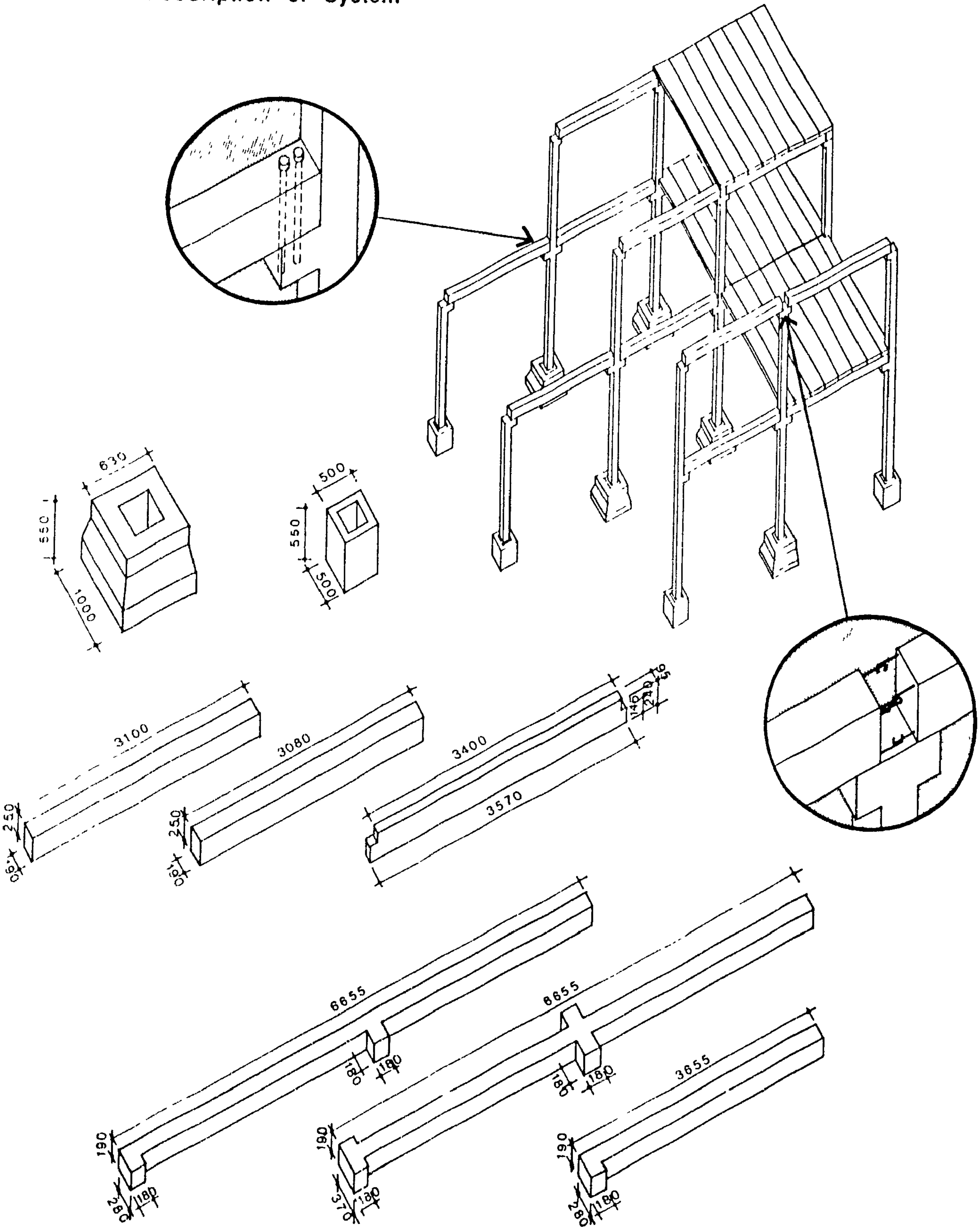
1. Introduction

In the Hanchuan region where this system was applied, there exists two kinds of conventional housing structure. One is timber frame infilled with adobe bricks wall and covered by clay tile roof. The other is burnt brick load bearing wall structure with hollow slab floor and roof. Nowadays, timber structure is no longer affordable and the use of burnt brick is also to be restricted because it destroys cultivated land and consumes much energy.

The Hanchuan system was designed to replace the conventional systems. It was regaided as being durable, anti-flood and seismic, as well as economical and fast in erection.

The unique feature of System is in the joint design. The joints between columns and beams in floor parts are bolted which ensures the speed of assembling. The joints in the roof parts are concrete in-situ. This ensures the stiffness of the structure and also no temporary supports are needed for the curing process of in-situ joint.

2. Description of System

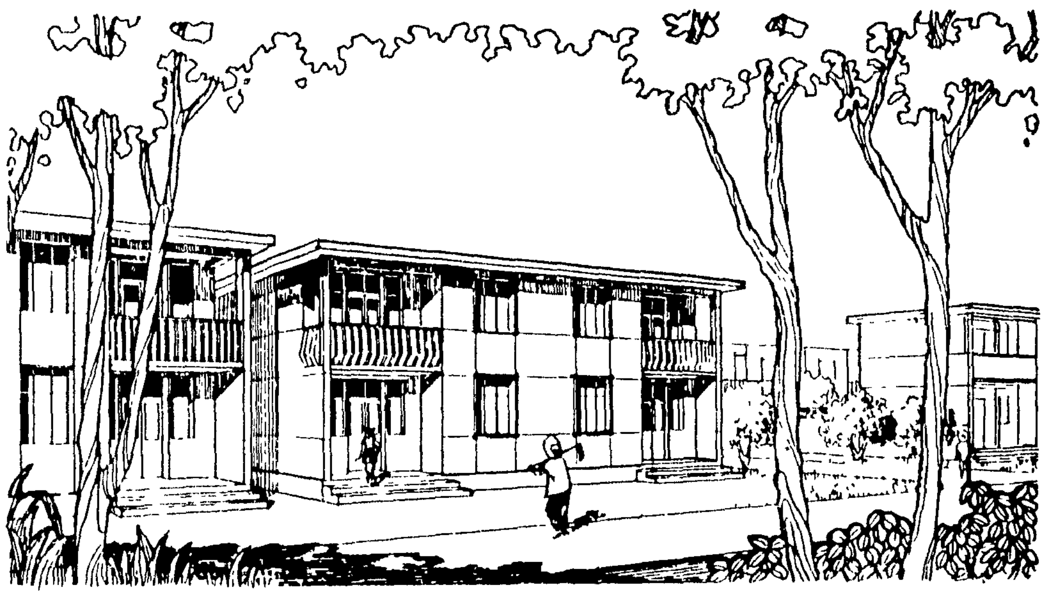


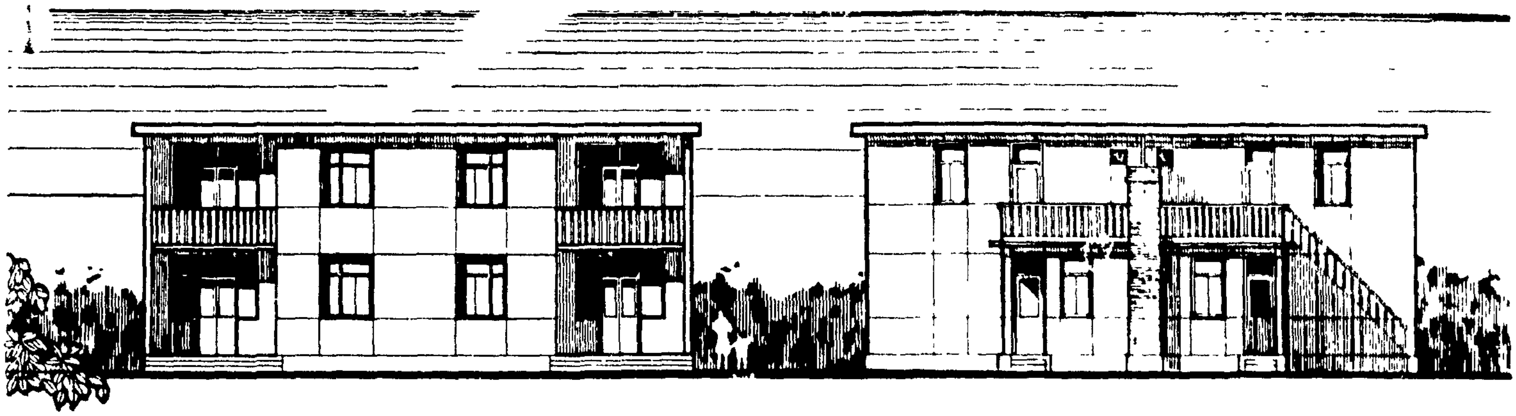
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	This component system was not designed for the simple small manufacturer.
	Mechanical device	It needs simple devices to manufacture and handle the components
Transportation		Components are difficult to transport because they are heavy and long
Construction	Kinds of components	There are eight kinds of components in the system
	Weight	Components are very heavy, the footing is 794kg, the column is 522kg.
	Equipment	The locally available farming lifting device, called "bagandiao" is used.
	Speed	7-8 persons can finish the erection of the frame part of the prototype house in one day.
	Special requirement	No special requirement.
Architectural feature	Interior flexibility	Interior flexibility is very good on the first floor.
	Extension	System it self can not be extended.
Flexibility in application		System can use different roof/floor components.

4. Prototype Project

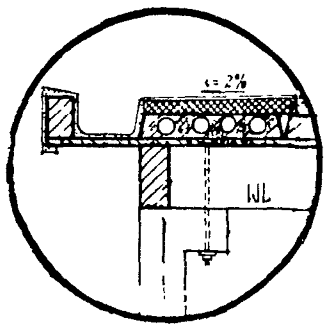
It is a two story suburban farmer's house, built by the farmers themselves or by a small contractor employed by them. The floor used hollow slabs which are wildly used in that area. Fly ash hollow block (190x190x390, 190x190x190, 190x190x95) was employed for the wall in order to promote the use of fly ash, which is rich in the area and was not fully used before.

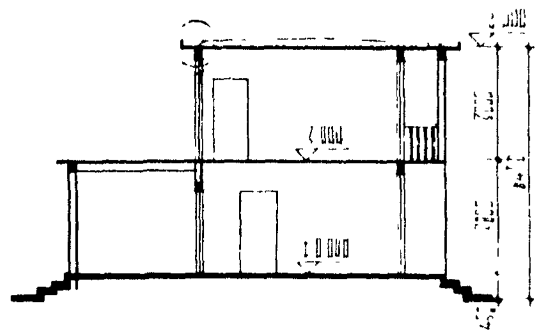




FRONT ELEVATION

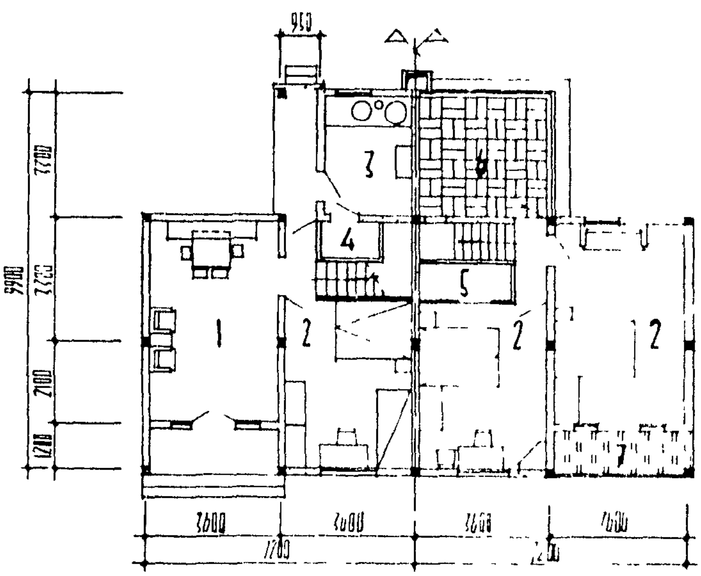
BACK ELEVATION





SECTION

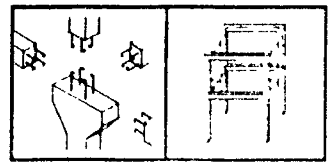
1. Living Room
2. Bed Room
3. Kitchen
4. Storage
5. Closet
6. Terrace
7. Balcony



FIRST FLOOR

SECOND FLOOR

SYSTEM'S NAME: ANJU[7]



DESIGNER AND DEVELOPER:

STATUS: Prototype houses was built

SUB-CLASSIFICATION: Earthquake resistant

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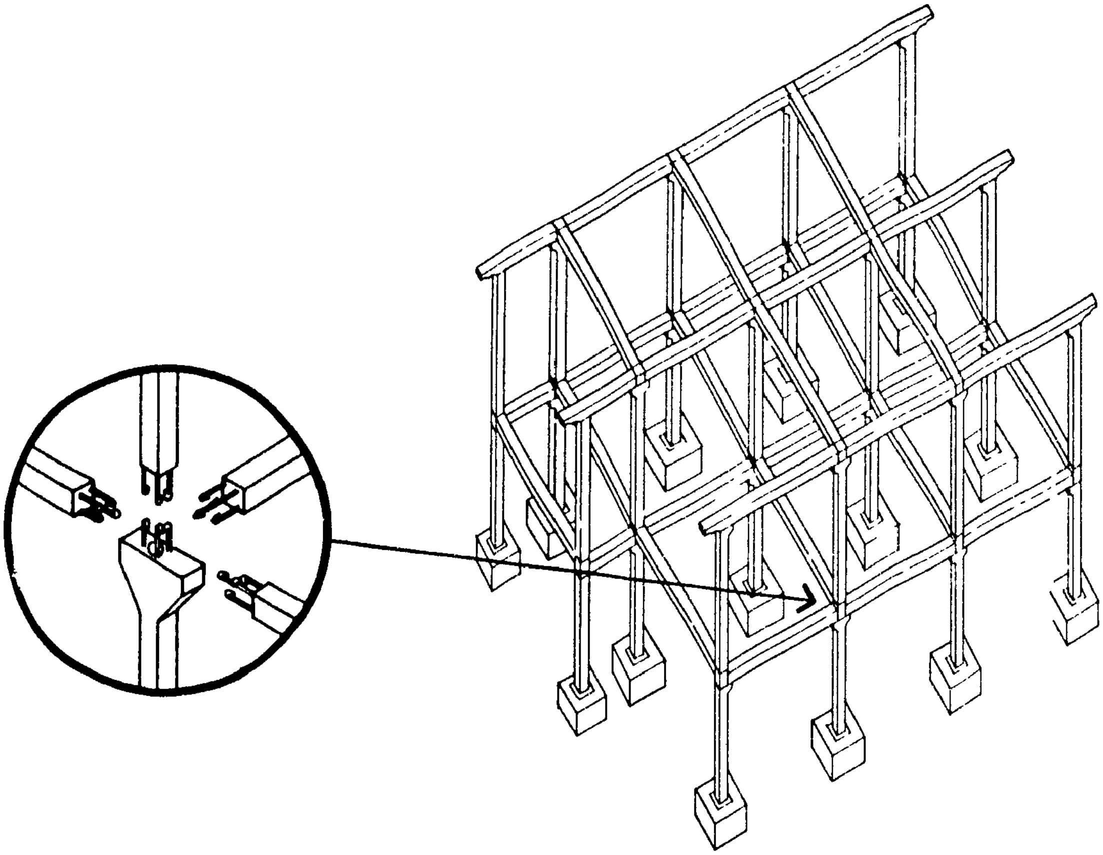
1. Introduction

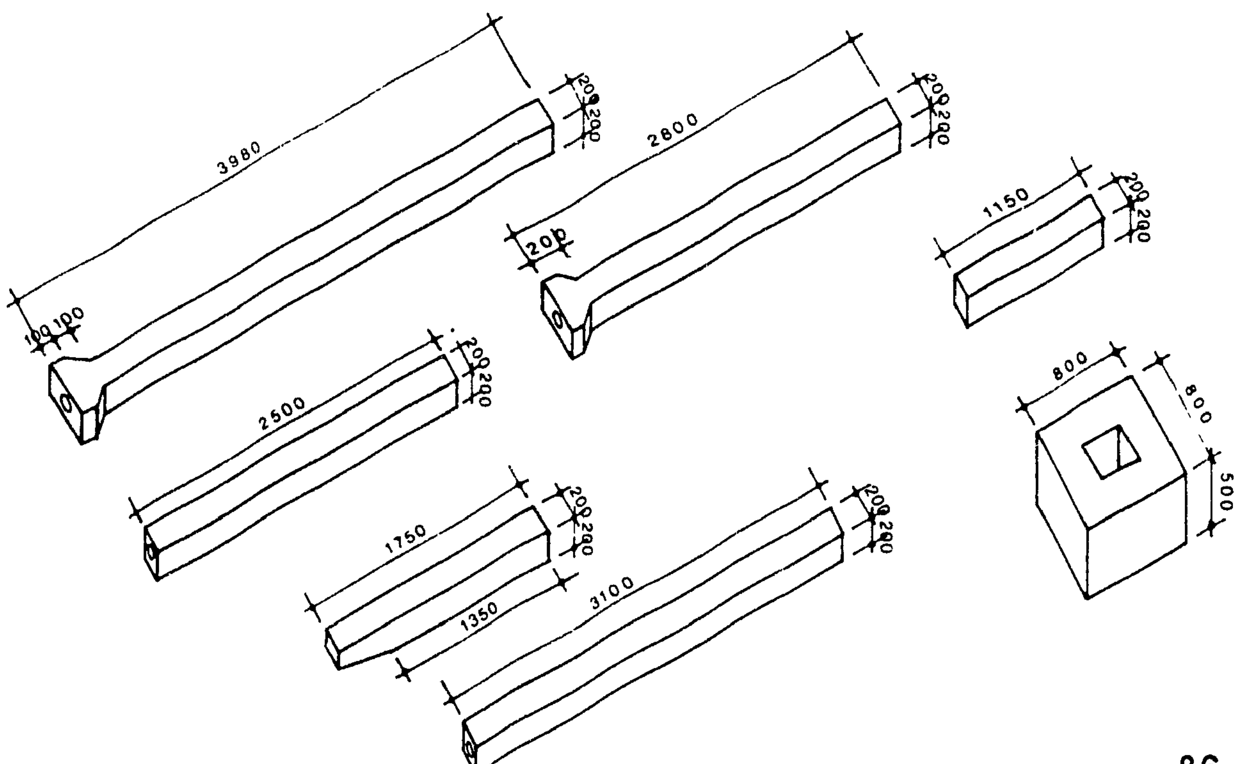
In China, the development of small towns has brought a new study topic -- the design of mixed use houses. The key point is to accommodate the commercial and residential activities within one house. The commercial activity needs large space and flexibility in layout while residential activity requires individual rooms.

With the traditional load-bearing wall structure, this requirement is difficult to be satisfied. The Anju system presented here is an innovative technical solution to this problem. The skeleton system provides a flexible interior space on the first floor. It can be arranged and re-arranged according to the needs of its occupants.

The column in the system is one story high, the erection of column on second floor and construction of the in-situ joint are difficult due to the heavy weight of components.

2. Description of System





3. The Evaluation from Design Consideration

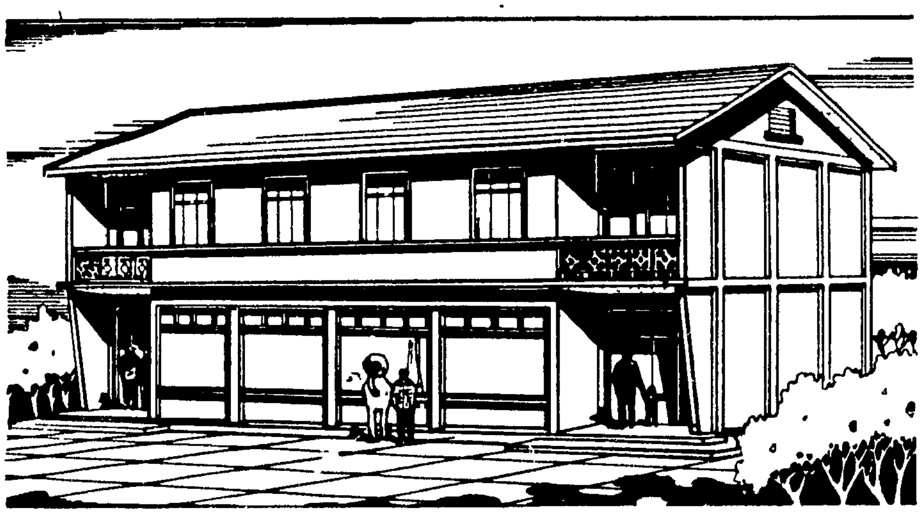
Major Consideration	Criteria	Comment
Manufacture	Form of components	Components are simple to make
	Mechanical device	Lifting device is needed for manufacture
Transportation		There is no problem in transporting the components
Construction	Kinds of components	There are six kinds of components in the system
	Weight	Components are very heavy, the footing is 662kg, the column is 374kg.
	Equipment	Lifting device is needed.
	Speed	It can not be very quick due to the in situ joints, especially the joints on the floor level take time for curing
	Special requirement	No special requirement
Architectural feature	Interior flexibility	Interior flexibility is very good on the first floor.
	Extension	System itself can not be extended
Flexibility in application		System can use different roof/floor components

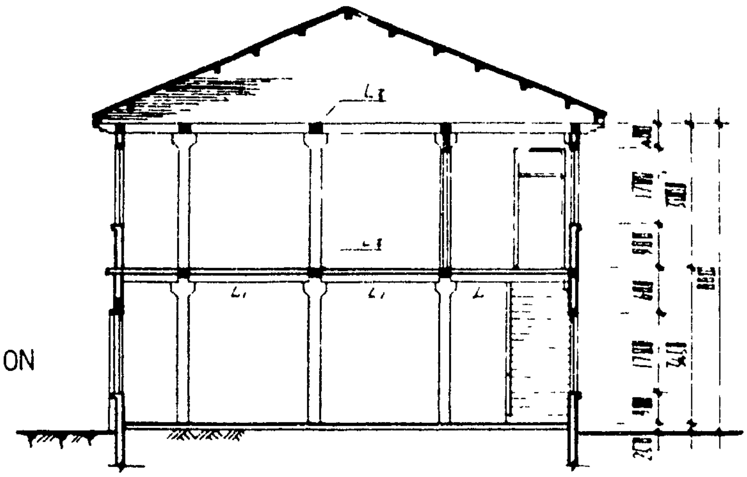
4. Prototype Project

The prototype project was a two story mixed use house.

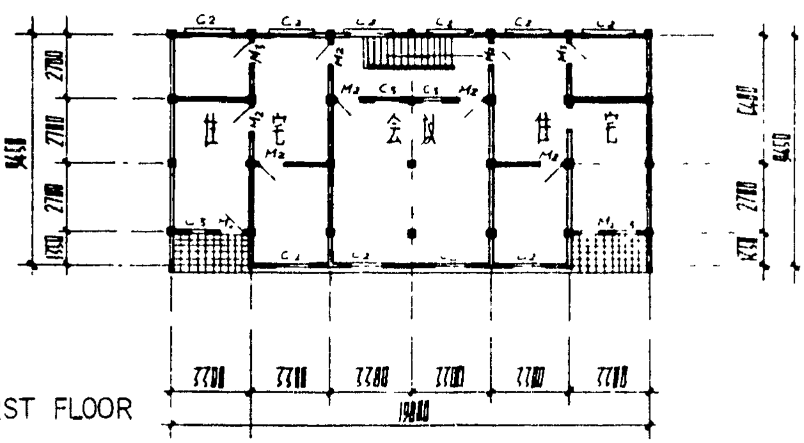
It used burnt clay hollow blocks for the outside wall and adobe bricks for the interior walls. The pitched roof was built using precast concrete reinforced beams and joists covered by clay tiles. These are local products and easily available.

The structural design was based on the multiple function of the house. For pure residential houses the reinforcement used in components can be reduced.

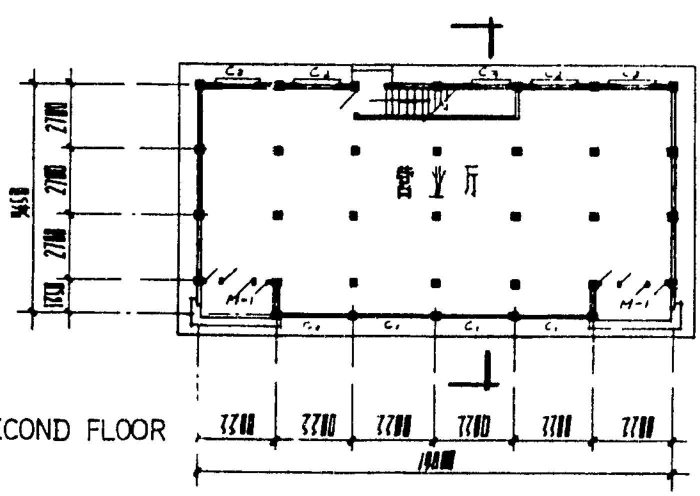




SECTION

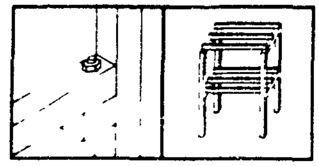


FIRST FLOOR



SECOND FLOOR

SYSTEM'S NAME: Xinti[8]



DESIGNER OR DEVELOPER:

STATUS: Eight prototypes were built in Hong Hu County, Hubei, China

SUB-CLASSIFICATION: Flood-resistant & Fast erection

---

1. Introduction

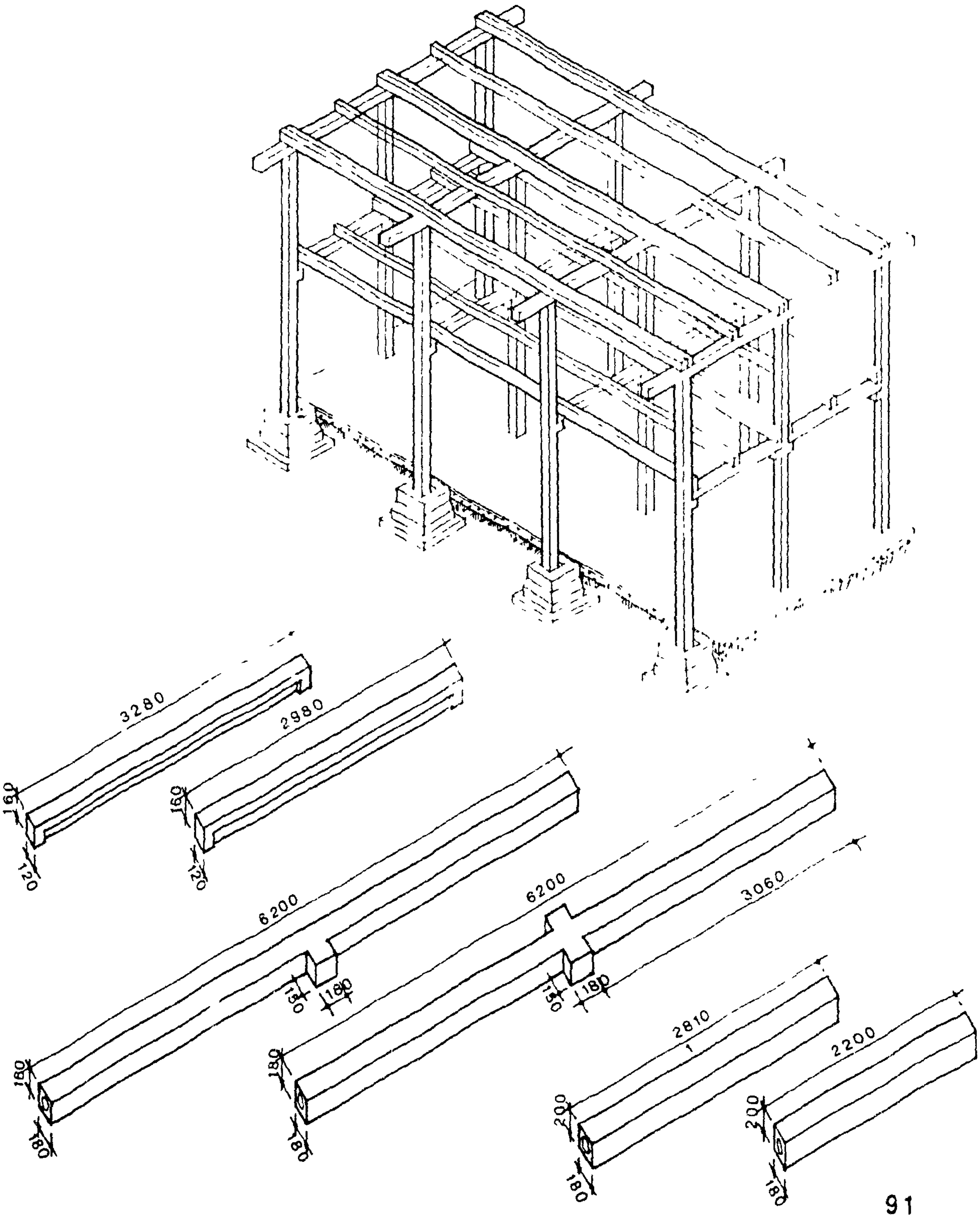
The Xinti system was developed for anti-flood houses in rural and sub-urban areas

Previously, people living in traditional single story houses would be homeless when floods came, therefore more and more people now build two story burnt brick houses, so they can live on the second floor during a flood. But when the bricks on the first floor were soaked in the flood and needed to be replaced, the upper floor structure would be in danger.

This problem was proposed to be solved by the employment of a skeleton structure. With the skeleton, the wall on the first floor can be easily repaired and replaced without threatening the upper floor. The designer also suggested that the wall on the first floor could be designed as portable components. Before the flood came, the users could move these components to the second floor and assemble them again after the flood receded

Although columns in the system are two story high, they are relatively light.

2. Description of System



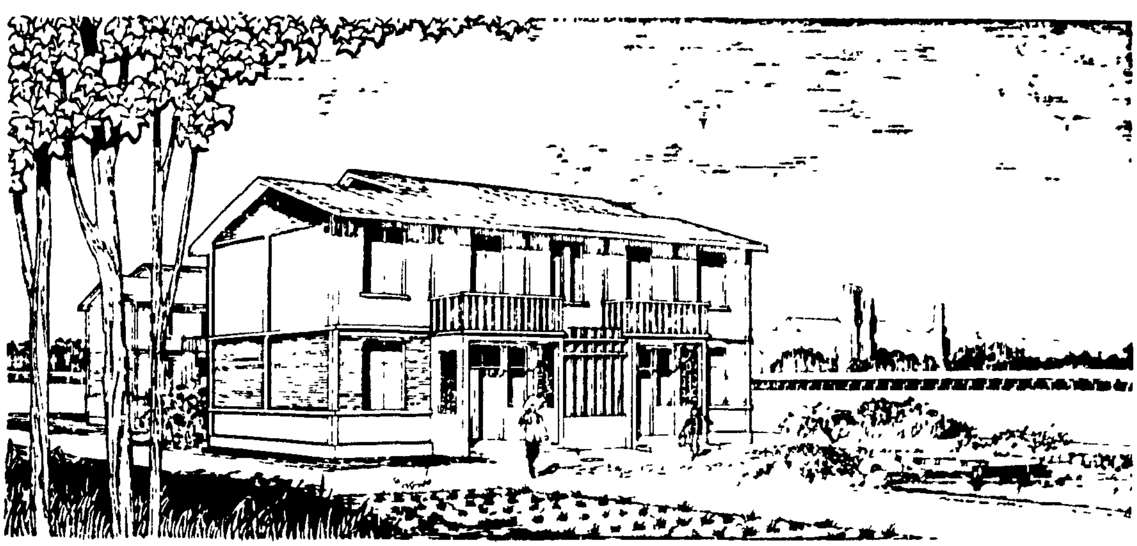
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are not very simple, but they are easy to make in a small factory.
	Mechanical device	The centrifugal machine is employed to make the hollow columns. It can be replaced by the galvanized iron tube to make the hollows.
Transportation		Components are not easy to transport because they are longer size
Construction	Kinds of components	There are six kinds of components in the system
	Weight	The column is heavy, about 332kg, this is reasonable for a two story high column. But it may be heavier for improving the thin cover of reinforcement in the bottom of column
	Equipment	The locally available farming lifting device, called "bagandiao" is used.
	Speed	It is immediately load-bearing, therefore it is fast to erect
	Special requirement	No special requirement
Architectural feature	Interior flexibility	Interior flexibility is very good on the first floor, good on the second floor.
	Extension	System itself can be extended
Flexibility in application		System can use different roof/floor components

4. Prototype Project

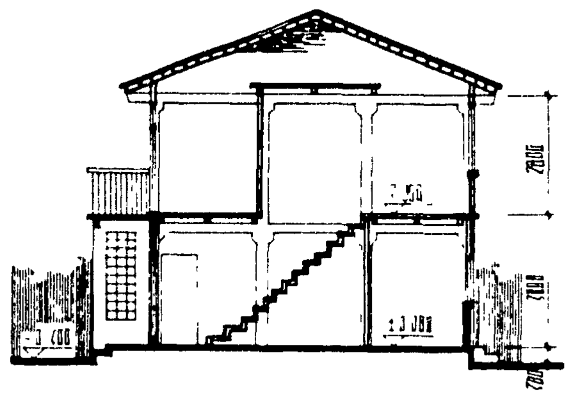
The prototype is a two story farmer's house. The concrete skeleton was used for its support structure and 12cm burnt bricks for the exterior wall on first floor. Hollow slabs made from magnesite concrete, which was a local product, were used for the floor and the rest of the walls. Experimentally, some partition parts used bamboo or reed marsh material

Eight prototype houses were built in 1982. Plans were made to gradually replace all the other structures with this system

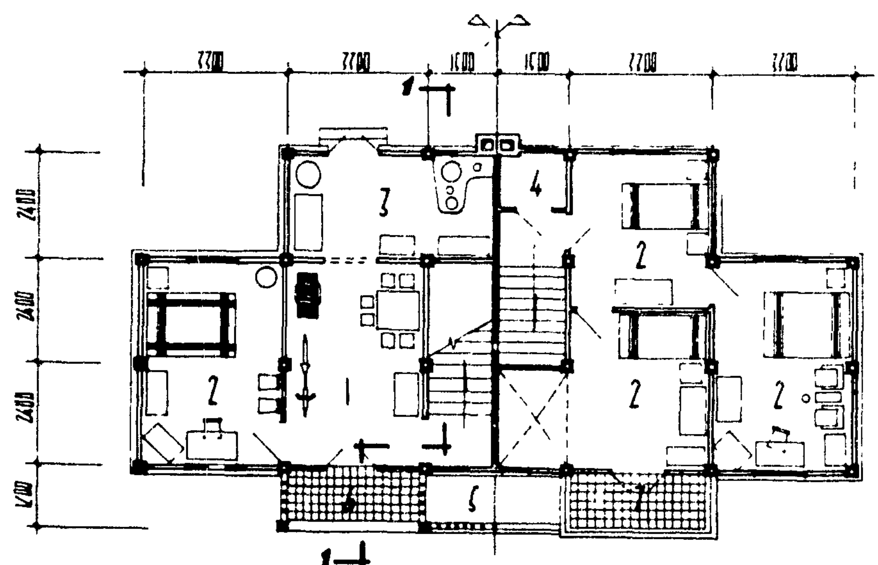


FRONT ELEVATION

SIDE ELEVATION



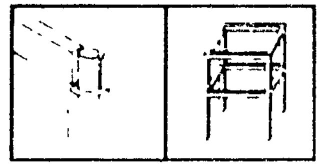
1. Living Room
2. Bed Room
3. Kitchen
4. Storage
5. Light Well
6. Porch
7. Balcony



FIRST FLOOR

SECOND FLOOR

SYSTEM'S NAME: BARCARES LEUATE[9]



DESIGNER OR DEVELOPER:

STATUS: It was applied to different buildings in France

SUB-CLASSIFICATION: Fast erection & free expansion

- -

1. Introduction

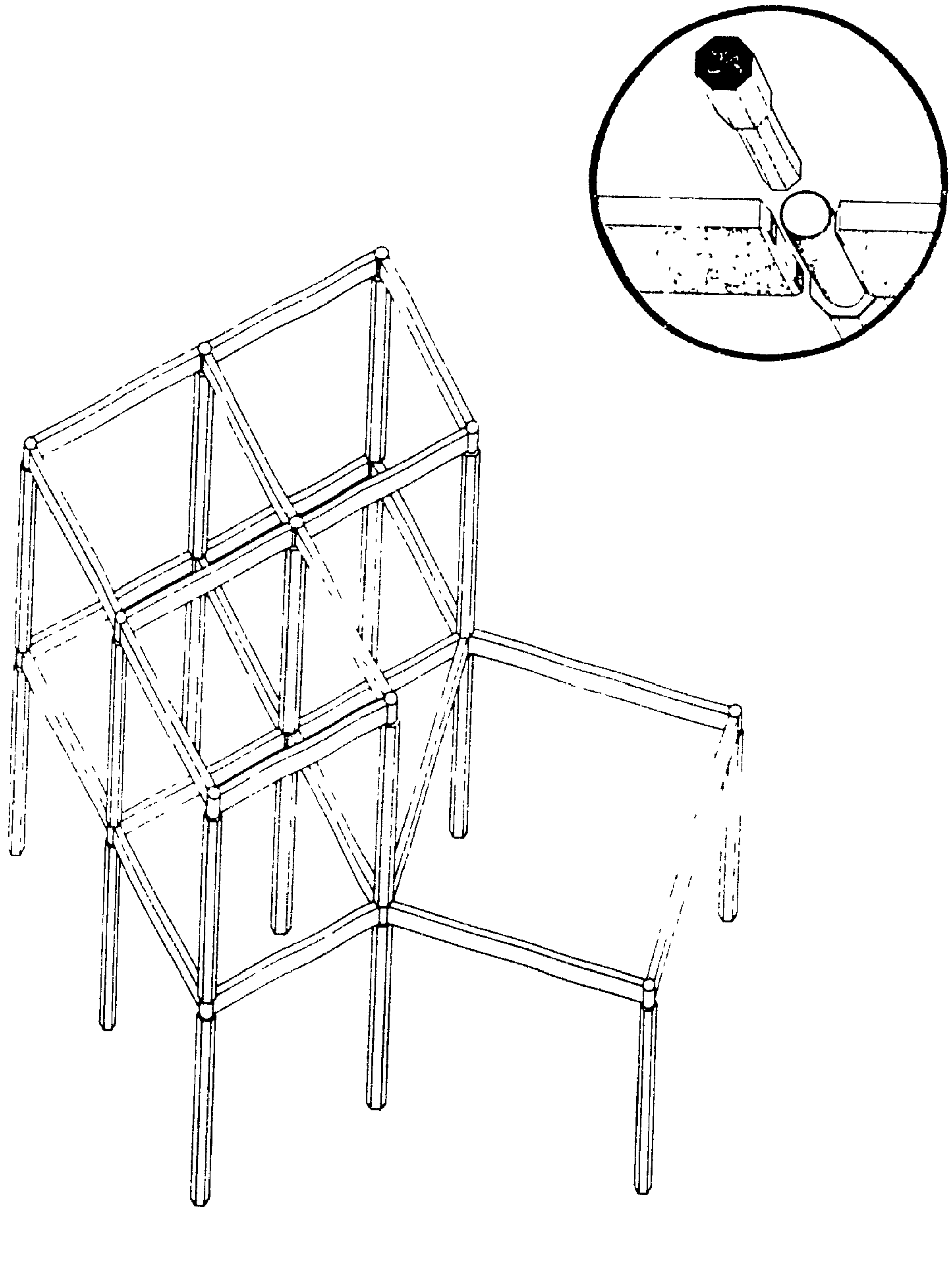
This system aimed at fast erection, easy manufacture and transportation and flexibility in design It is suitable for housing but not specially designed for it.

The design of the system is characterized by two points:

1) Minimum number of components, which are simple and easy to make. Basically the system has only four components -- a column, two beams and a steel capital. Therefore, it is easy to produce and transport. Also, the beam can be a conventional one with embedded steel plate That means the new components are only column and capital. Thus to adopt this system does not require big investment at initial stage.

2) The design of the joint between column and beam. It has two advantages First, the connection can be quickly done with a welding machine. Second, the beam can link with the column in any direction on horizontal level. Therefore it does not require high accuracy and allows greater flexibility in plan.

2. Description of System



3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	The form of the components is simple, but it needs a special form to make it.
	Mechanical device	No mechanical device is needed
Transportation		There are no problem in transportation
Construction	Kinds of components	There are four kinds of component in the system
	Weight	No data available
	Equipment	It needs a welding machine at least
	Speed	Fast, load-bearing immediately
	Special requirement	No special requirement
Architectural feature	Interior flexibility	Interior flexibility is very good on the first floor.
	Extension	System itself can be extended
Flexibility in application		The components could be used with other systems

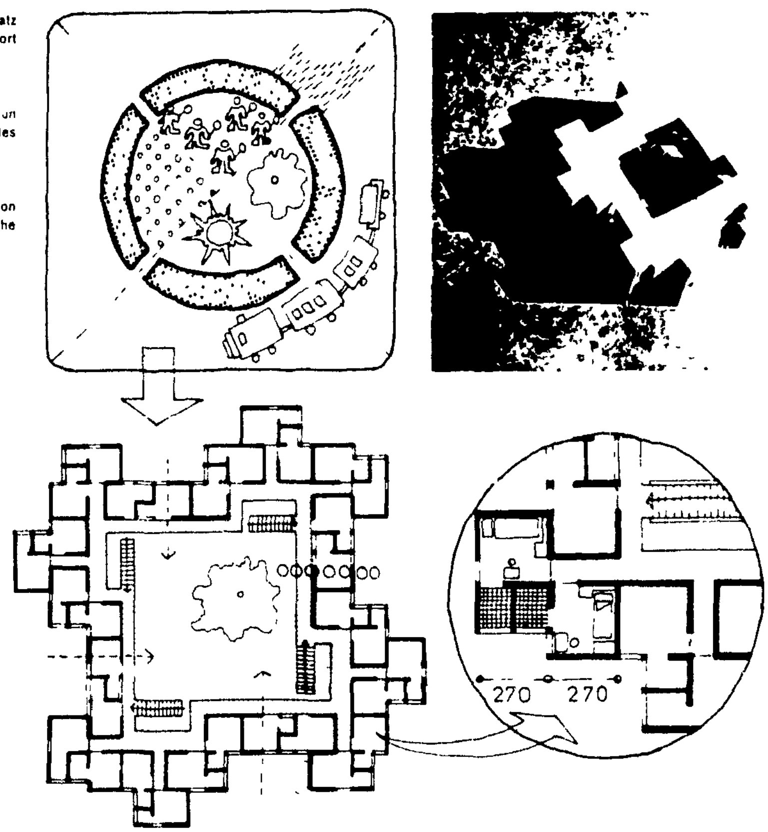
4. Prototype Project

The prototype project was a youth club and hotel which could be used as a house. The system had also been used to build other instant buildings in the tourist areas in France.

Ein geschutzter Kinderspielplatz und das Jugendhaus von Port Leucate

Sur la plage de Port Leucate un abri pour les enfants la cité des jeunes

A play shelter for children on the beach at Port Leucate the youth club (and hostel)

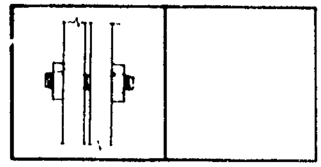


SYSTEM'S NAME: Match Stick[10]

DESIGNER OR DEVELOPER: K.C.Soni

STATUS: At least 2000 houses were built by 1974, India

SUB-CLASSIFICATION: Earthquake resistant



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1. Introduction

This system was developed for two or three story apartments in the mountain regions, where conventional construction materials and labour were difficult to get, many laborers were employed from outside. Therefore it was important to use local material, avoid heavy transportation, reduce on site work and make it simple so that untrained labour could do the bulk of the work, the use of heavy machinery and equipment could be avoided. The system was designed to resistant earthquake.

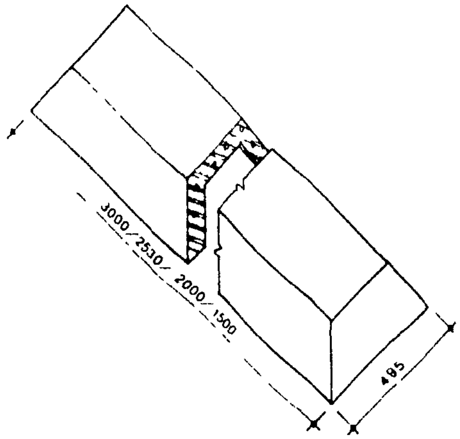
To reach the targets, the following ideas were applied in this system:

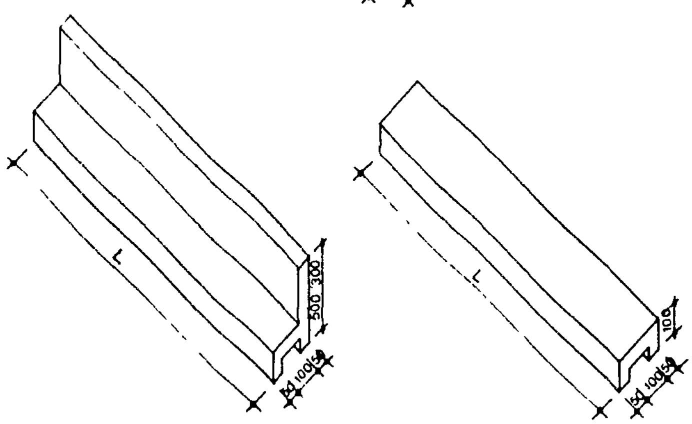
a. all the components were prefabricated including the covering components for the wall. The major on-site work was simply bolting the components together

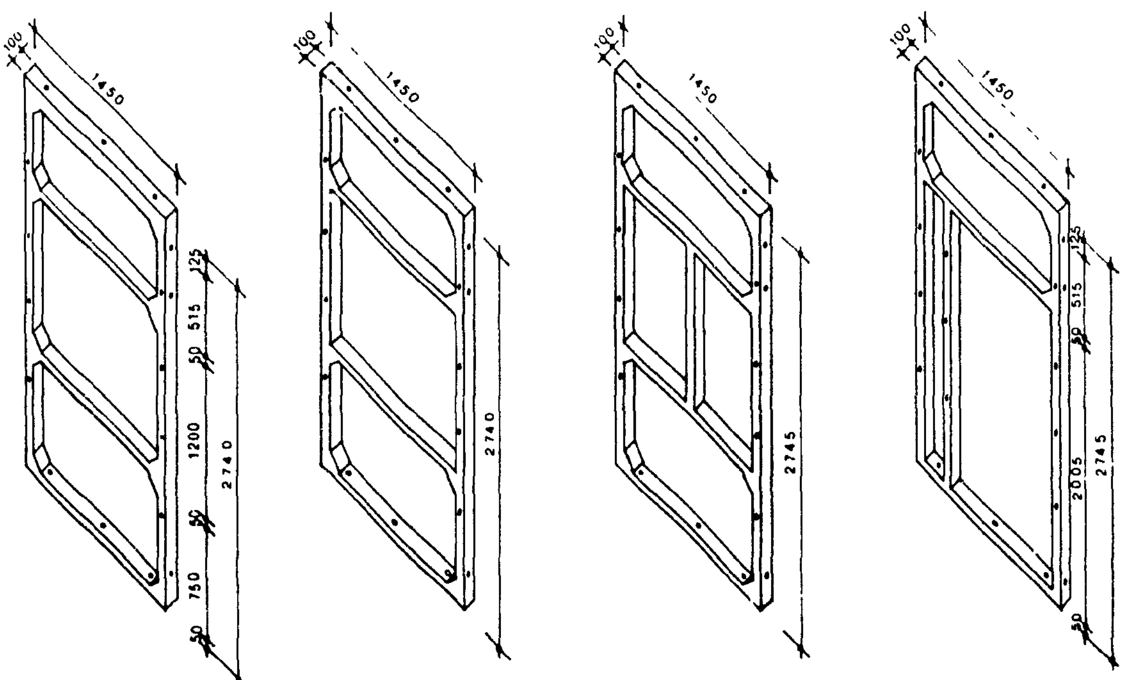
b. the weight of the components was limited to 240kg and were designed to be handled easily.

c. roof spans could be up to 4.88m for different buildings.

2. Description of System







3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are simple in form. Due to the small sections, careful work is needed in making them.
	Mechanical device	No mechanical device is needed.
Transportation		There is no difficulty in transportation
Construction	Kinds of components	There are five kinds of components in the system
	Weight	The wall frames are heavy, but no problem for manually handling by three persons.
	Equipment	No equipment is needed.
	Speed	The assembly is mainly dry work and load-bearing immediately, therefore the speed is high
	Special requirement	The frame panels should be ensured to be perfectly vertical when being erected
Architectural feature	Interior flexibility	Interior flexibility is limited by existing wall frame.
	Extension	system itself can not be extended
Flexibility in application		System can use different roof components

4. Prototype Project

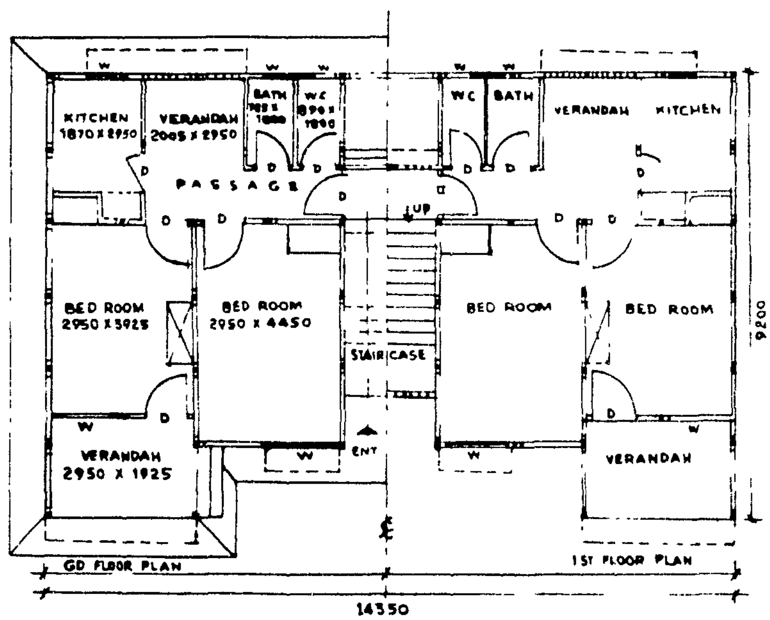
The prototype project was a three story apartment houses, built by the contractor.

The erecting procedure of the house was conventional. First foundation was completed, then the wall frame of the first floor was erected, and floor troughs was placed on the top of the panels. The procedure was repeated for the second and the third floor.

The external and internal cladding on the wall panel was of lath plaster on G120 gauge chicken wire netting of 1/2" mesh. The specification for cladding as adopted allows for a hollow space of about 3", which could be filled in with any insulating material depending upon the local requirements.

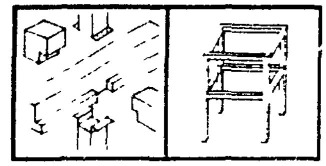
A Panoramic View of Housing Complexes

CLOSE VIEW OF APARTMENT HOUSE



TYPICAL PLAN

SYSTEM'S NAME: Mitchell Frame[11]



DESIGNER OR DEVELOPER: Neal Mitchell

STATUS: Prototype houses were built
in Lancaster, U.S.A in the Late 1960's

SUB-CLASSIFICATION: Fast erection & free expansion

---

1. Introduction

In 1964, the designer had developed a SPCSS for a one story self-built house for developing countries, aimed at simple and easy construction. Later, the basic idea was developed into the Mitchell Frame. This frame allows the growth of the house and can sensitively reflect its users' needs.

There are three main characteristics in the system.

1) Flexibility in house plan

This system can be expanded in any direction. The key to this is in the design of components The column is designed for four story load-bearing and the joint is bolting with steel plate on the top of column.

2) The adaptability to changes

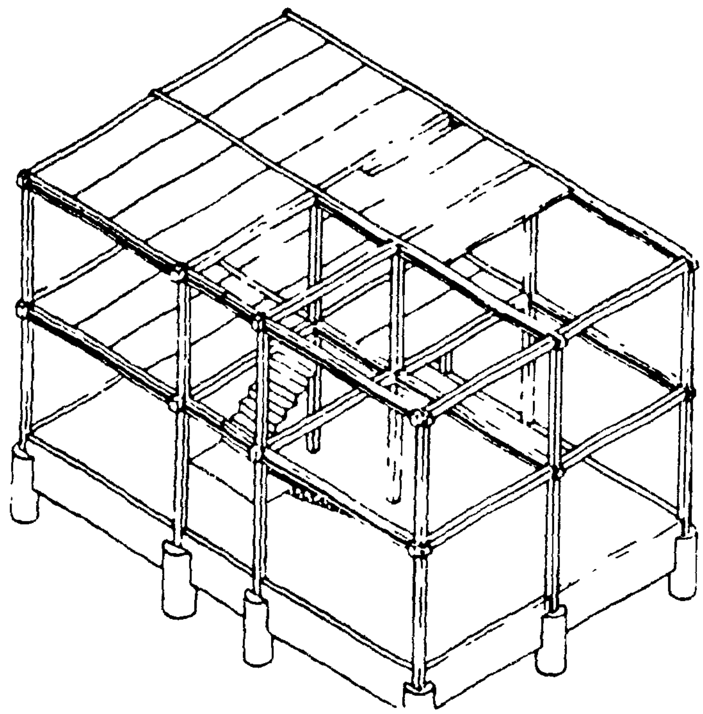
The system **recognizes** that different building parts wear out at different rates and they should be able to be replaced or upgraded with time; on the other hand, the users' financial abilities, tastes and needs are always changing. The Mitchell frame adapts to these changes by employing different materials depending on the climate, the budget and the owners' taste. In the prototype project, for example, the light panels which can be bolted in or un-bolted are used. The designer foresees the day when the components of the system are available in local retail outlets, " A guy could remove a wall, take it down to the hardware store, and trade it in for a better wall. Then somebody else could buy the second-hand wall".

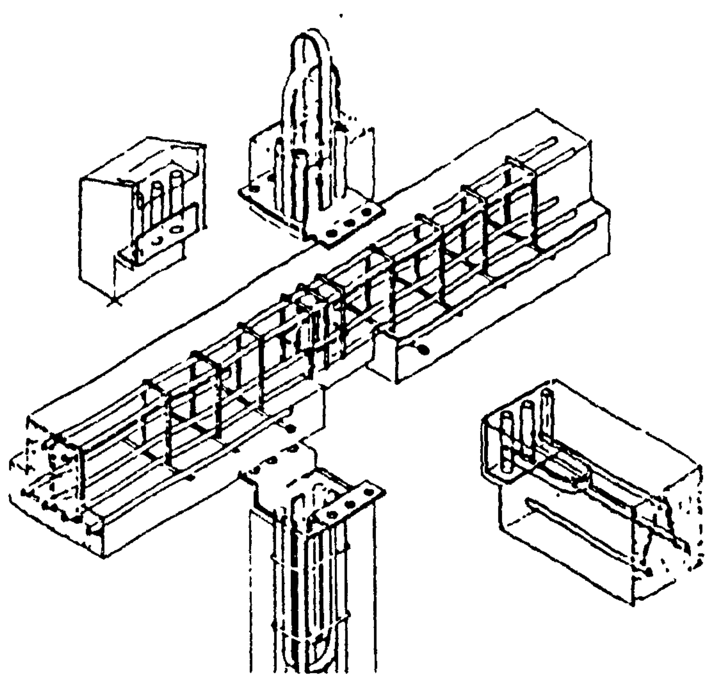
(3) Simplify the on-site job

The system is also specially designed for simplifying the on-site job. First, the weight of the components is reduced by using light weight "foam" concrete, which is about half as heavy as the regular concrete. Only two workers are needed to lift the column and the beam. Secondly, the number of the components are limited to only five kinds -- a column, a cantilever beam, two tie beams and a slab The column of the first floor is the same as the column on other floors. Finally, the construction is simplified by the simple connection system of a step by step bolting procedure. The columns and beams can be easily assembled and locked together, so that un-skilled workers can not make mistakes. The assembling procedure is as follows: first, the columns are locked into pockets embedded in precast cylindrical footings, then the beams are fitted into the connecting hardware on the columns, lastly the floor-roof slab is placed atop the beams, and 2-in layer of cellular concrete is poured over the precast slabs. Then the partition walls are fastened to the concrete frame.

The design of this system demonstrated fully the potential flexibility of the skeleton system for low-cost housing.

2. Description of System



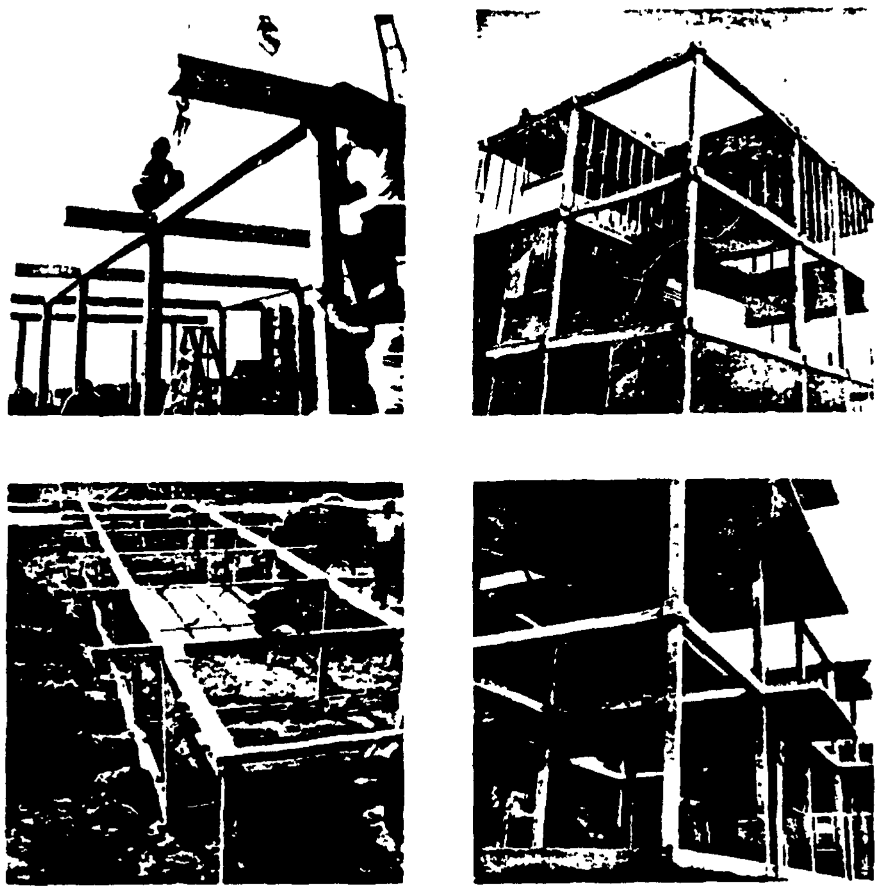


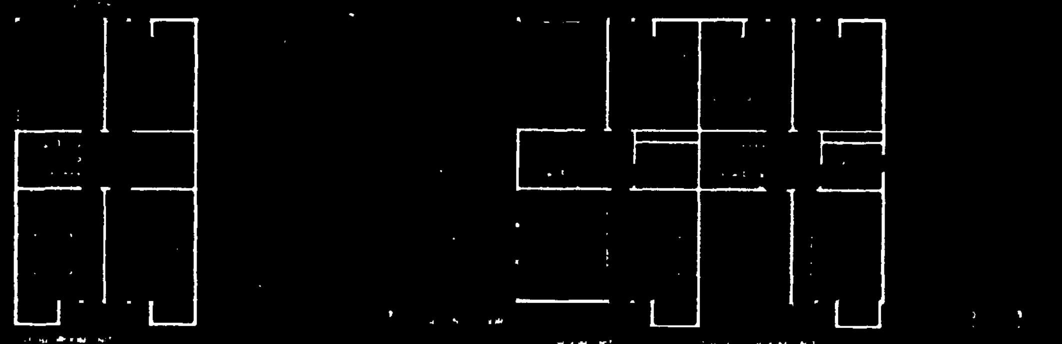
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components Mechanical device	The form of the component is simple, but the joint parts are complicated for small manufacturer, their manufacture need the help of the mechanical devices
Transportation		There is no difficulty in transportation
Construction	Kinds of components	There are five kinds of components in the system
	Weight	Components in the system are light, they can be carried by two people
	Equipment	For multi-story houses, lifting device is needed
	Speed	The assembling work is simple, immediate load-bearing, therefore the speed is high
	Special requirement	The location of the components should be accurate to ensure the accuracy of the bolting
Architectural feature	Interior flexibility	Interior flexibility is good
	Extension	System itself can be extended
Flexibility in application		System can use different roof components

4. Prototype Project

This was a group of one to three story town houses in Lancaster, U.S.A. But they houses were not an exhaustive demonstration of the Mitchell system. According to Robison's report, this system has been used in other developing countries..



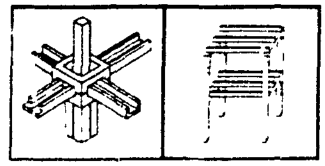


Mitchell's modular system (erection sequence opposite) is adaptable to an almost infinite variety of shapes and sizes. The three Lancaster town houses have amenities not usually found in low-cost housing: generous decks, balconies, large closets, and spacious kitchen-dining areas. The five-bedroom unit has a two-story-high living room.

SYSTEM'S NAME: M.I.T.[12]

DESIGNER OR DEVELOPER: M.I.T

STATUS: Prototype houses were built in Cairo University



SUB-CLASSIFICATION: General use & earthquake resistant

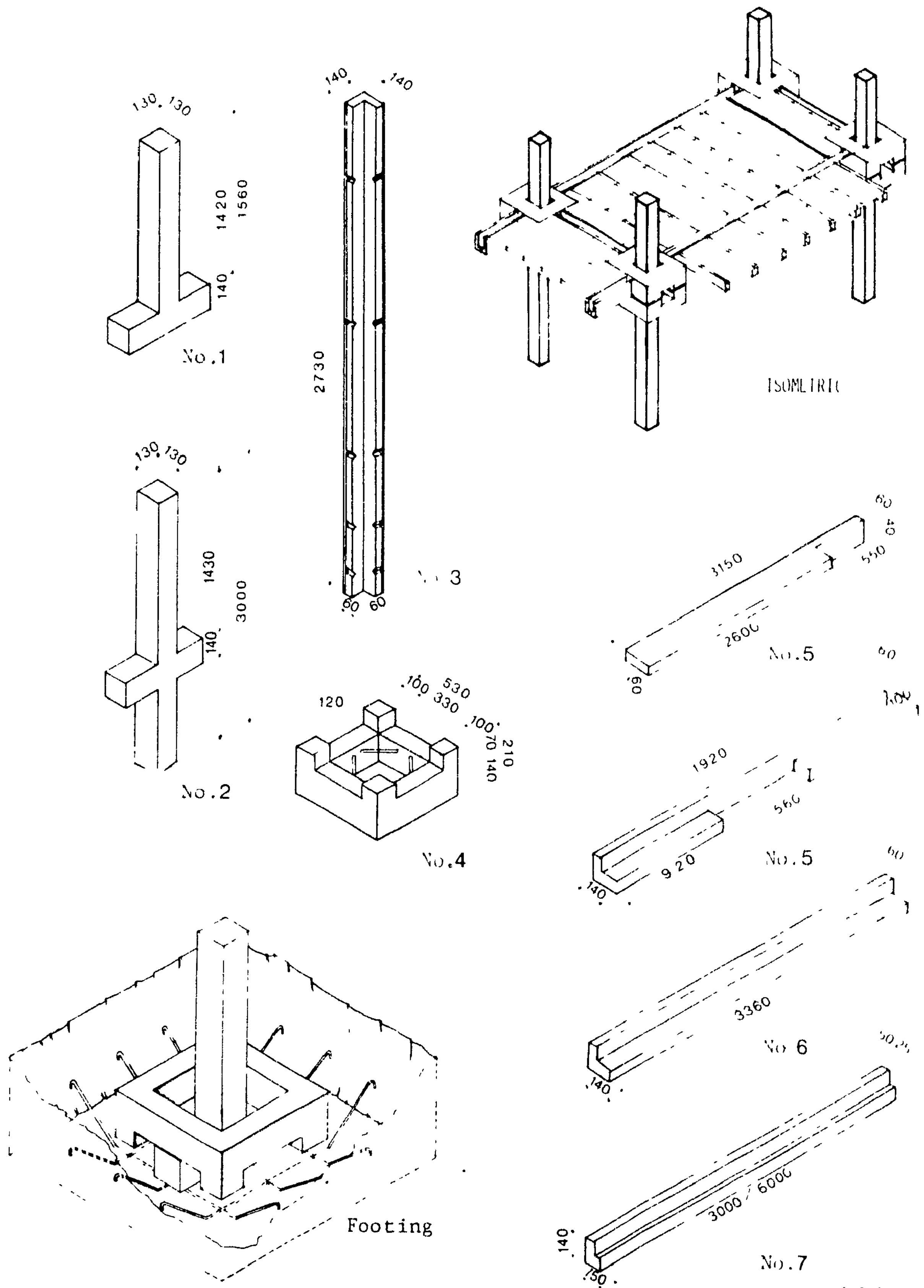
---

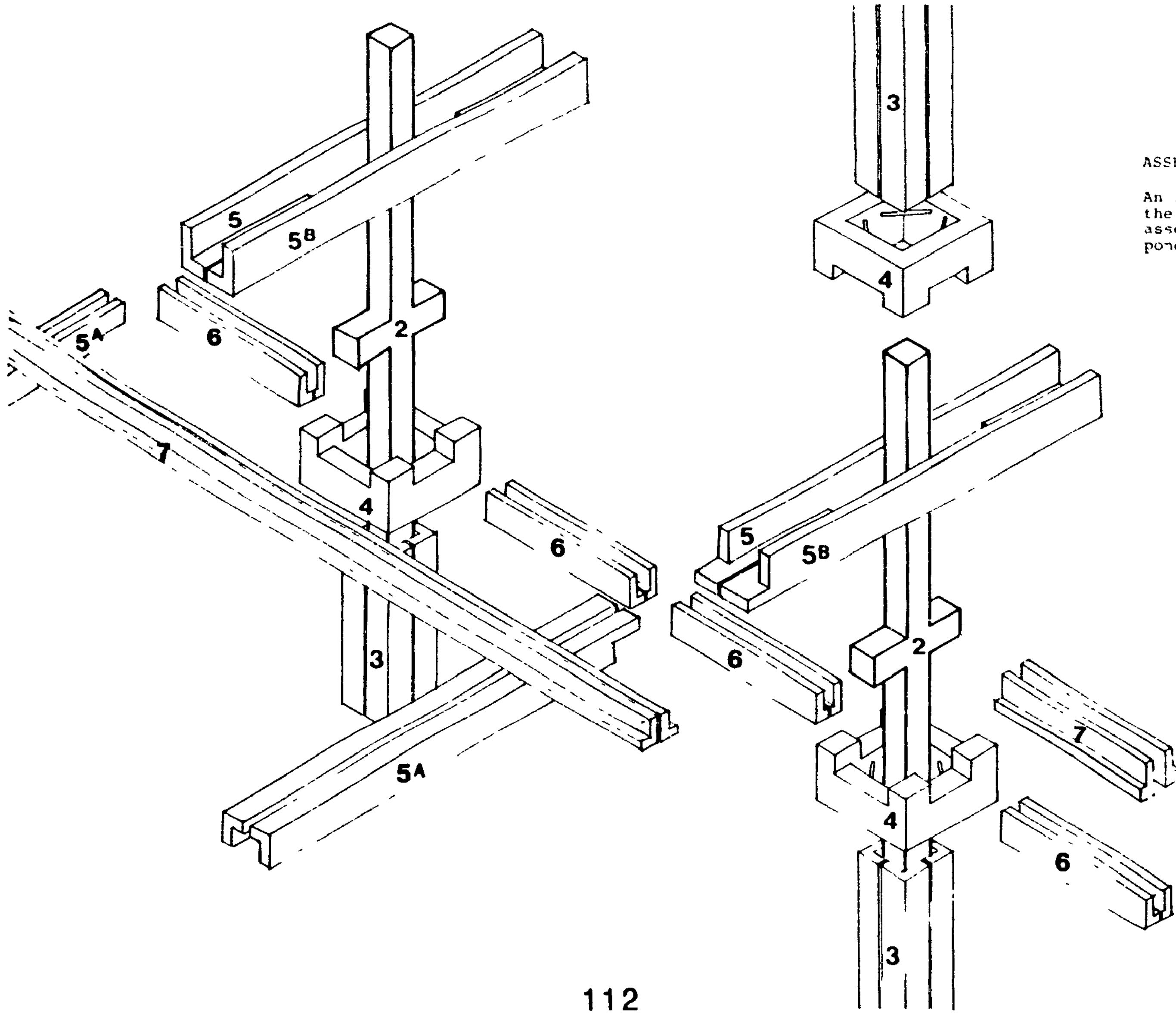
1. Introduction

Housing in and around Cairo mostly consist of in-situ cast reinforced concrete frame structure with brick infill for facades and partitions. It was decided to develop a rationalized prototype of "small components", which would consume less steel and cement, with lightweight elements, and be capable of accepting alternative materials for internal partitions other than traditional clay bricks. The "Light Component" system was initially proposed in 1979 for application to core housing types of 1-2 storey high only. Consequently, applications for 4-5 story structures were included. The design was conceived on the basis of the following criteria:

1. All of components are light and small enough to be carried by 2-4 workers.
2. All elements of the structure may be cast either on or off site in simple wood or metal forms
3. The system acts as its own scaffolding.
4. The system distinguishes between PRIMARY (structural, long-term use, essential) "support" elements, and SECONDARY (non-structural, medium to short term use, optional variable) "infill" elements.

2. Description of System





ASSEMBLY SEQUENCE

An isometric showing the whole sequence of assembly and all components of structure.

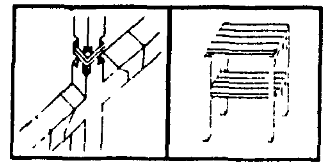
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components Mechanical device	The form of the components are complicated, but they are small in size and can be manually handled. It is a sophisticated design and need more accurate form work
Transportation		There is no difficulty in transportation
Construction	Kinds of components	There are eight kinds of components in the system
	Weight	Components can be carried by four people.
	Equipment	Theoretically, the system can be built manually, but equipments will facilitate the assembling work for multi-story house.
	Speed	No report on its speed. But obviously, it can not be fast due to the complicated procedure
	Special requirement	No special requirement
Architectural feature	Interior flexibility	Interior flexibility is very good
	Extension	System itself can not be extended
Flexibility in application		It is a closed system

4. Prototype Project

There was one experiment project reported, which is used as a shop in Cairo university. No details about it have been documented.

SYSTEM'S NAME: ORLIT[13]



DESIGNER OR DEVELOPER: Orlit Ltd.

STATUS: Approx.17,000 houses built in UK by 1956

SUB-CLASSIFICATION: General use & flood resistant

---

1. Introduction

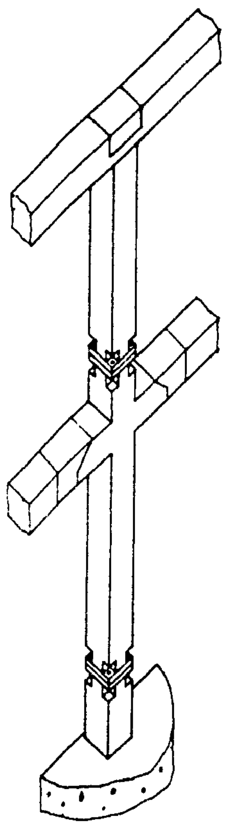
The Orlit system was developed in 1940's. It is one of the alternative construction systems for post war housing approved and subsidized by the British Government at the time.

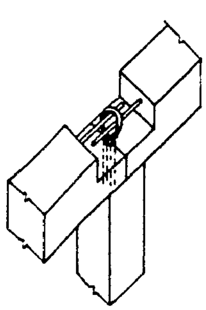
This system can adapt to almost any plan, elevation and type of buildings, with the advantage in cost, speed of erection and minimum consumption of timber and steel. The benefits of standardization are obtained not by offering standardized buildings, but by standardized sections of component units of a wide range of sizes. The section of the columns, beams and other framing members depend on the number of storeys, spans, floor loadings, etc., but the same connection between members is maintained.

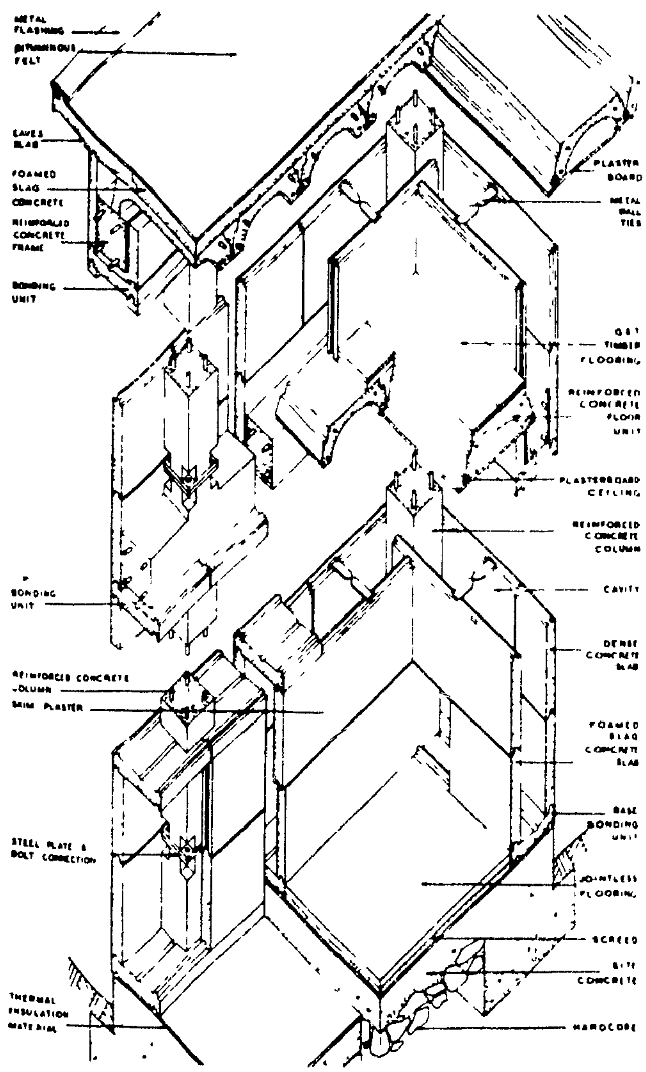
It differs from the other systems in the way that manufacture of all constructional units were done on the site. By using the mobile cranes, the problem of the weight of the components was overcomed; therefore it is possible to make big span components for different building types.

2. Description of the System

The details of the system is varied, and the variations are mainly in floor components. The system shown here is a simple one. The space between columns is about 10-12 ft. The section of column is around 6.75 in.x 6.75 in..





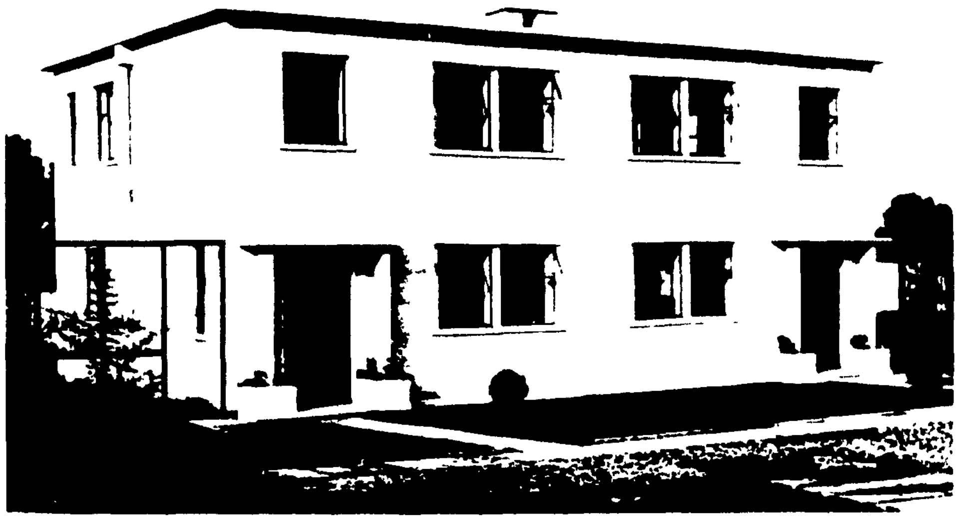


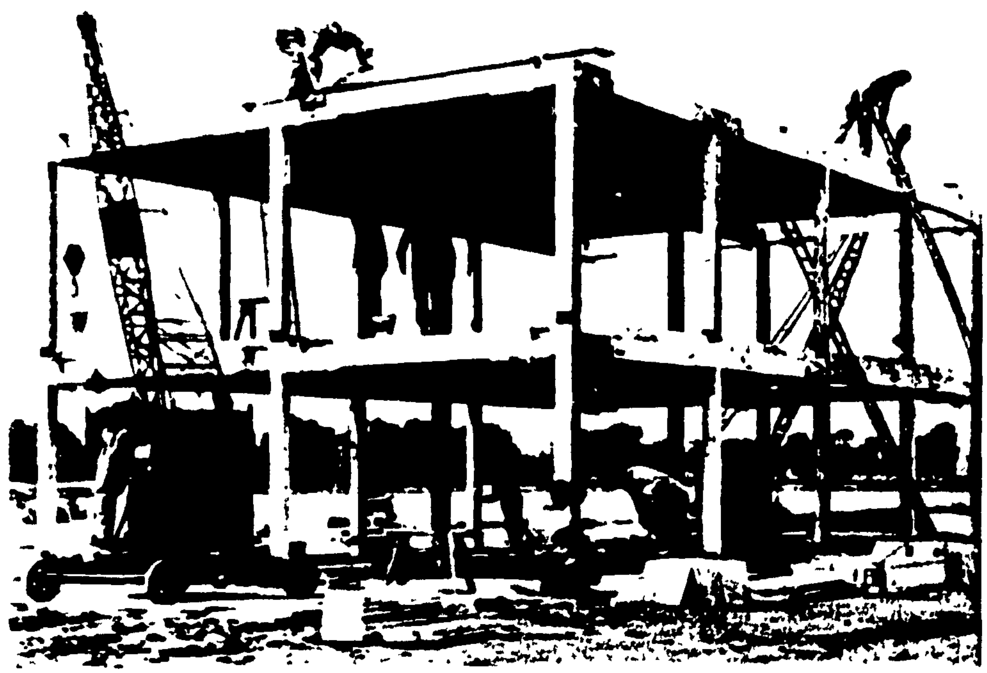
3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components Mechanical device	The form of the components are simple, but the joint design is sophisticated, it needs help from the equipment.
Transportation		On site prefabrication.
Construction	Kinds of components	Basically five components
	Weight	The components are very heavy.
	Equipment	Mobile cranes are needed
	Speed	Slow due to the in-situ joints
	Special requirement	No special requirement
Architectural feature	Interior flexibility	Interior flexibility is very good
	Extension	System itself can not be extended
Flexibility in application		This system has several variations, all of them are closed systems

4. Prototype

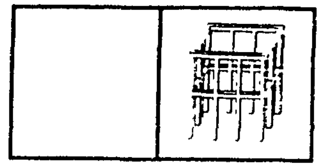
There were 17,000 Orlit houses built. The details of its construction system in different areas were varied, but the same principle of connections between members was maintained. The roof of house can be either flat or sloped.





The frame and floors complete.
Note the mobile cranes.

SYSTEM'S NAME: AIREY14



DEVELOPER: Wessrs. Wm. Airey
and Son Ltd.

STATUS: Approx.26,000 houses had been built in UK by 1955. It was also reported to be built in Netherlands

SUB-CLASSIFICATION: General use

---

1. Introduction

Airey system is developed from the Duo-slab system. Duo-slab was a precast cavity wall system with an in-situ column system. In Airey system, the columns were changed to precast and the system became such that it was produced in "highly organized" factories and served to many small, scattered, rural and semi-rural sites.

The system consisted essentially of precast posts and slabs, of small enough dimensions for all pieces to be manually handled. This is the main feature of the system.

2. Description of the System

The Airey house is a prefabricated concrete box structure which is formed from closely spaced 62.5 cm apart, storey-height wall columns (104mm x 57mm in cross-section and reinforced longitudinally with a small tube) to which thin concrete cladding panels are fastened with copper wire. There is internal spine wall constructed similarly with columns of 75mm x 57mm cross section. The first floor and floor beams are bolted to the columns.

The components was made by dense concrete and they were very light.

Posts	----	70-80lbs
Slabs	----	37lbs
Corner slabs	----	42lbs
Floor beams	----	37lbs

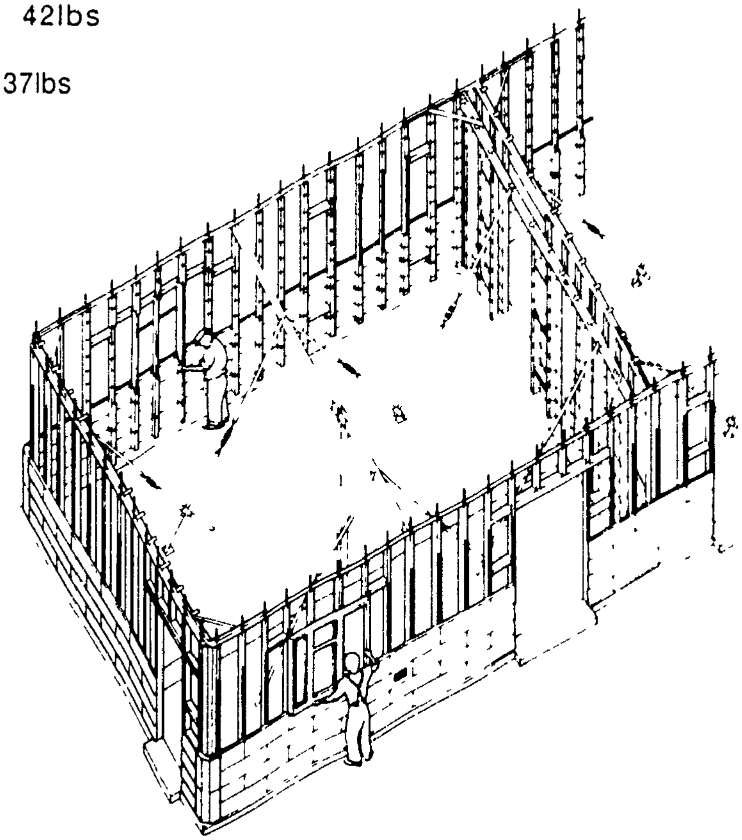


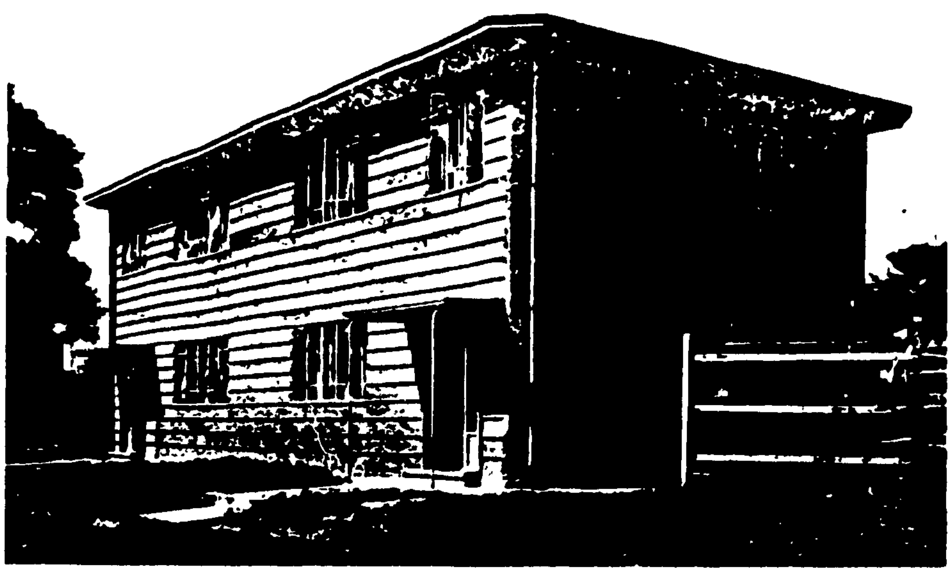
Illustration of an Airey house during construction (ground first floor level)

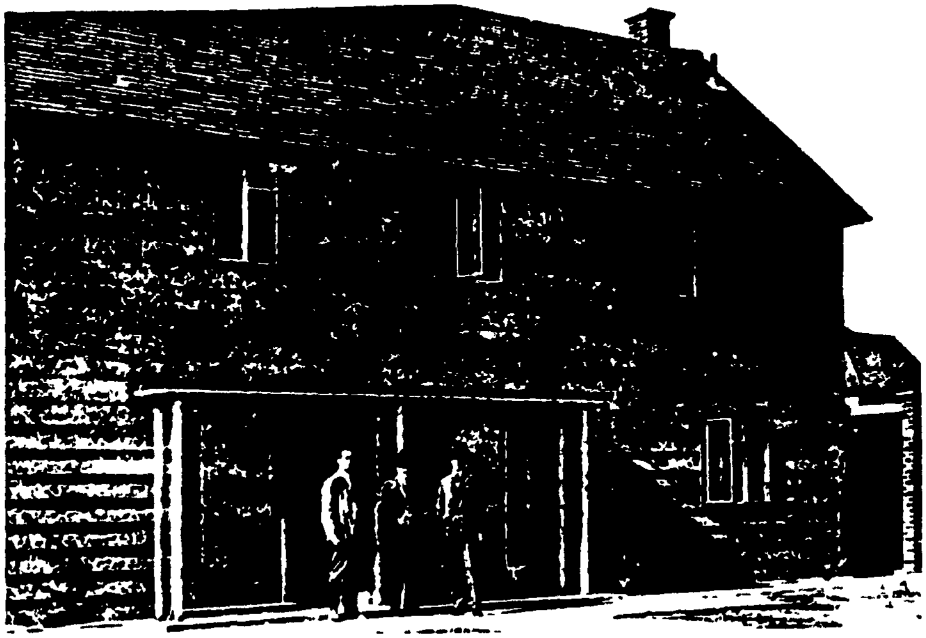
3. The Evaluation from Design Consideration

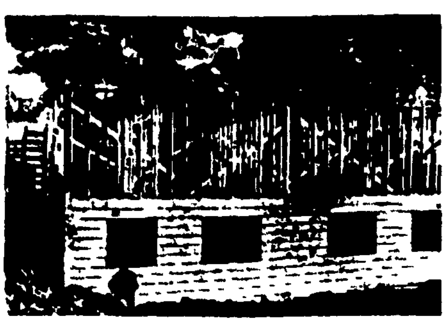
Major Consideration	Criteria	Comment
Manufacture	Form of components Mechanical device	No available information to do the judgement
Transportation		No problem in transportation
Construction	Kinds of components	No available information
	Weight	It is very light, Max.80lb two persons can handle it.
	Equipment	No equipment is needed
	Speed	No report on its speed, but the simple assembling procedure and dry on-site work will facilitate the speed
	Special requirement	No special requirement
Architectural feature	Interior flexibility Extension	Interior flexibility is limited System itself can not be extended
Flexibility in application		This system is a closed system

4. Prototype

There were 26,000 Airey houses built. They are mainly two story semi-detached houses. The roof may be pitched for rural area or flat for the city. Its external "wall is covered with precast reinforced concrete slab laid dry and wired to the posts with copper hooks embedded in the slabs. Each course of slabs overlaps the course below so giving weathered joints which shed the rain. The vertical joints which are also without mortar occur always in front of post" (Fitzmaurice 361). This treatment gives a traditional cottage look Using concrete material to imitate the traditional style was popular in this stage of development of SPCSS.





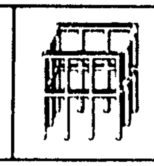


SYSTEM'S NAME: WOOLAWAY[15]

DESIGNER OR DEVELOPER: W.Woolaway & Sons Ltd.

STATUS: Approx.5500 houses had been built in UK by 1956

SUB-CLASSIFICATION: General use



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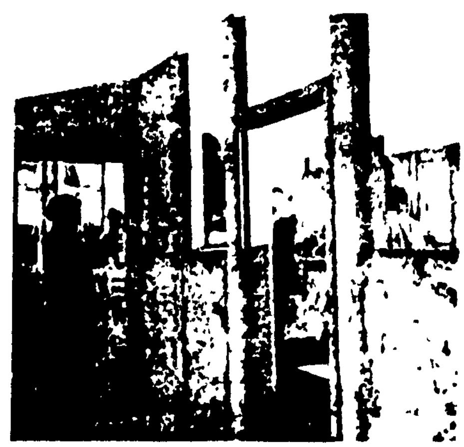
1. Introduction

Woolaway is one of the many post-panel precast systems developed in UK in the 1940's. This basic idea of post-panel has been widely used. For example, the Sandino system in Cuba was similar. In a later development, the cavity wall was replaced by the sandwich panels.

The use of air-entrained concrete for beams and slab is the special feature of this system. It is an early experiment of using air-entrained concrete, and its success in lasting over 30-40 years up to now show the latent possibilities of this material used in SPCSS structure.



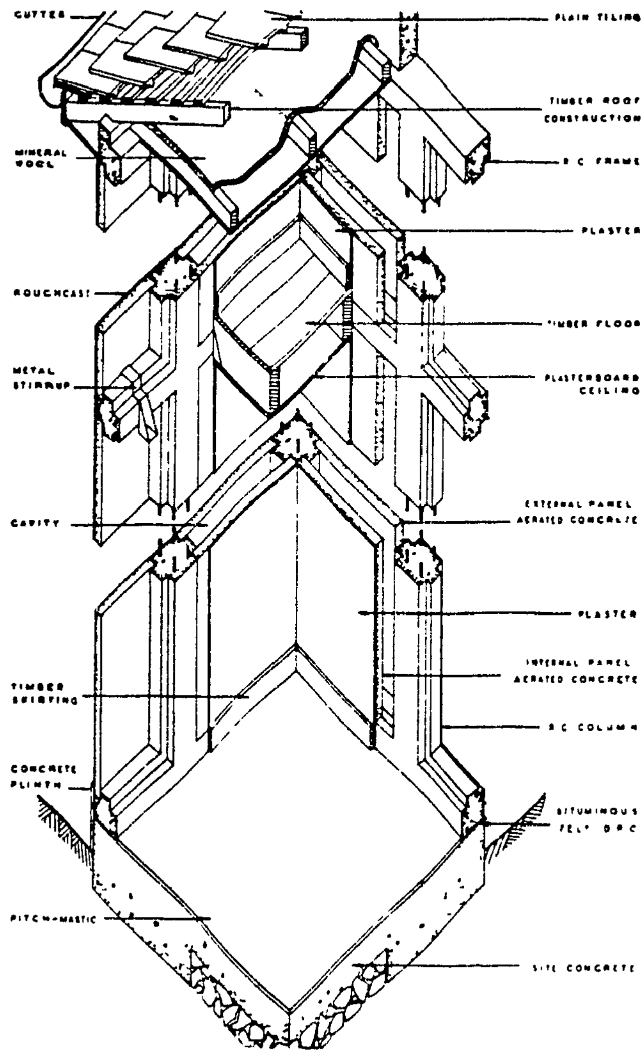
2. Description of the System

The system is mainly composed of posts and panels. The story high posts are spaced at 2 ft 6 in. centers, are 6 in. square in section with 2 in. square projections on two sides, forming rebates to receive the panel members and the half story high wall panels are bolted to the columns with six bolts. Therefore, no mortar is used in erection of posts and panels.

Posts 222lbs

Slab 104lbs

(Fitzmaurice 359)



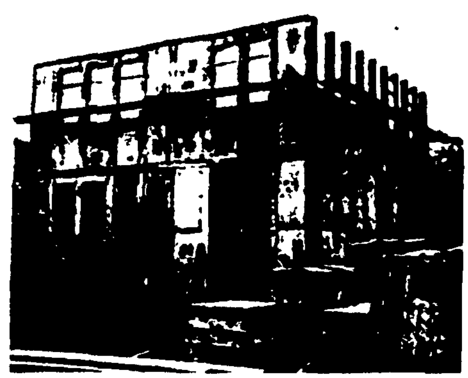
WOOLAWAY HOUSE

3. The Evaluation from Design Consideration

Major Consideration	Criteria	Comment
Manufacture	Form of components	The components are simple
	Mechanical device	No available information
Transportation		There is no problem in transportation
Construction	Kinds of components	No available information
	Weight	It is light, Max.222lb two persons can handle it.
	Equipment	No equipment is needed
	Speed	Dry work lead to a fast assembling
	Special requirement	Dimensional accuracy is absolutely essential due to bolt connection between post and wall slab
Architectural feature	Interior flexibility	Interior flexibility is limited
	Extension	Information is not enough.
Flexibility in application		This system is a closed system

4. Prototype

The Woolaway houses are mainly two story semi-detached or row houses. It uses the conventional pitched roof structure. The gable ends of the roof being infilled with block work. The structure of the houses is hidden from view externally by rendering.



Summary

The information provided in the previous case studies are basically limited to the design stage of the systems. Neither is much information available on the systems' application, nor on the post-evaluation of the application. The economy of a certain system was often mentioned however, either from system design point of view, like the saving of materials by careful design, or in comparison with the locally used systems, but the argument usually lacked enough confidence and general value.

It is clear that the design of most SPCSS systems is simple, though some are more complicated. But it is true that they have seldom been put into practice. Majority of the systems are closed, which requires to adopt the whole package of components in application. The outstanding exception is the Grameen system, which is simplest in design, open in application and seems to be the most successful one according to the existing literature.

The general use of SPCSS were found in the early period. Later on the application of SPCSS were mainly limited to projects with special requirements, and mass application of SPCSS has rarely been reported.

THE SUMMARY INFORMATION OF THE SYSTEMS SURVEYED

Name of the system	Grameen System	Shan XI	APOPA	SINGH	GUPT
Status	Since 1984 to 1990, 59,000 houses have been built over Bangladesh	No reported utilization. Designed in 1984, Shan Xi, China	Prototype project was built in El Salvador, 1970's	Prototype was built in 1976	Protot in 19
Designed Function	Flood-resistant, fast-erection	Earth-quake resistant, fast-erection	Earthquake resistant	General use & earthquake-resistant	Earth- resista erecti
Description of System	• There is only one concrete compo-nents in the system and they are very simple in making, light in weight	• There are four kinds of components in the system and they are simple in making, but too heavy to be manually handled	• There are five kinds of components in the system and they are simple and light enough to be manually made and handled	• There are five kinds of components in the system and they are simple and light enough, to be manually made and handled	• Ther kinds in the needs in mar control and th are lig
	• No equipment is needed for construction and the system is fast in assembling	• Simple lifting device is needed for construc-tion and the system is load bearing immediate-ly, fast in assembling	• For the convenience, a simple lifting device is needed and the assembling process is simple and quick	• No equipment is needed for construction and the construction speed is low due to the curing of roof.	• No e needec constr is high
	• System can be extended easily and very flexible in interior layout	• System can be extended in one direction and very flexible in interior layout	• System itself can not be extended and Interior flexibility is very good	• System itself can not be extended and Interior flexibility is very good	• Syst can no and in flexibil by exi frame.
	• System is total inter-changeable	• System is totally inter-changeable	• System is totally inter-changeable	• System is not inter-changeable	•Syster differe compo

PTA	HANCHUAN	ANJU	XINTI	BARCARES LEUATE	Match Stick	Mitchell Fram
otype was built 980's	Five Prototypes were built in 1982, Hanchuan Hubei, China	Prototype houses was built	Eight prototypes were built in Hong Hu County, Hubei, China	It was applied to different buildings in France	At least 2000 houses were built by 1974 in India	Prototype house were built in Lancaster,U S A the Late 1960's
h-quake stant & fast ction	Flood and earth-quake resistant & fast erection	Earthquake resistant	Flood-resistant & Fast erection	Fast erection & free expansion	Earthquake resistant	Fast erection & free expansion
ere are four s of components e system and it ds supervision anufacture to rol the quality the components light	• There are eight kinds of components in the system, they are simple in form but too heavy and big for manually handle	• There are six kinds of components in the system and they are simple in form but too heavy for manually handle	• There are six kinds of components in the system, they are not very simple, but easy to make in a small factory, the column is heavy	• There are four kinds of component in the system and they are simple, but need a special form to make it	• There are five kinds of components in the system The wall frames are heavy, but no problem for manually handling by three persons	• There are fiv kinds of compor in the system a they are simple form, light in weight, they ca carried by two people.
equipment is ded and the struction speed gh	• The lifting device is needed and 7-8 persons finished the erection of the frame of the proto-type house in one day.	• The lifting device is needed and it can not be very quick due to the in situ joints	• The lifting device is needed and the system is immediately load-bearing, therefore it is fast to erect	• It needs a welding machine at least for assembling but fast, load-bearing immediately	• No equipment is needed and the assembly is mainly dry work, there-fore the speed is high	• For multi sto houses, lifting device is neede The assembling work is simple fast
ystem it-self not be extended interior bility is limited xisting wall e.	• System it self can not be extended and interior flexibility is very good on the first floor	• System itself can not be extended and Interior flexibility is very good on the first floor.	• System itself can be extended and Interior flexibility is very good on the first floor, good on the second floor.	• System itself can be extended and Interior flexibility is very good on the first floor.	• system itself can not be extended and interior flexibility is limited by existing wall frame.	• System itself be extended and Interior flexibi is good
tem can use rent roof ponents	• System can use different roof/floor components.	• System can use different roof/floor components	• System can use different roof/floor components	• The components could be used with other systems	• System can use different roof components	• System can u different roof components

	Mitchell Frame	M.I.T.	ORLIT	AIREY	WOOLAWAY
	Prototype houses were built in Lancaster,U.S.A in the Late 1960's	Prototype houses were built in Cairo University	Approx.17,000 houses built in UK by 1956	Min. 26,000 houses built in U.K. also be built in Netherlands	Approx.5500 houses had been built in UK by 1956
	Fast erection & free expansion	General use & earthquake resistant	General use & flood resistant	General use	General use
its ne	• There are five kinds of components in the system and they are simple in form, light in weight, they can be carried by two people.	• There are eight kinds of components in the system and its form are complicated, but they are small in size and can be manually handled	• Basically five components in the system , they are very heavy, the joint design is sophisticated, it needs help from the equipment.	• No available information on number of component, they are very light, Max.80lb two persons can handle it.	• No available information on number of component, they are light, Max.222lb two persons can handle them
iy	• For multi-story houses, lifting device is needed. The assembling work is simple and fast	• The equipments will facilitate the assembling work for multi-story house	• Mobile cranes was used, slow due to the in-situ joints	• No equipment is needed for assembling, the assembling is dry and simple on-site work will facilitate the speed	• No equipment is needed for construction and dry work lead to a fast assembling
in nd y	• System itself can be extended and Interior flexibility is good	• System itself can not be extended and Interior flexibility is very good	• System itself can not be extended Interior flexibility is very good	• System itself can not be extended and interior flexibility is limited	• Interior flexibility is limited
	• System can use different roof components	• It is a closed system	• All the variation of this system are closed one	• This system is a closed system	• This system is a closed system

SOURCES

CASE1.

(1) "Grameen Bank Housing Project" Mimar 33, December, 1989: 19-21.

(2) "The Grameen Bank Housing Loan Project" Mimar 34, March, 1990. 36-41.

CASE2.

(1) Fu Kuenyan, "The Study of the Structure System for Farmer's House", diss., China: Shan Xi Research Institute for Building Science, 1984 5

CASE3.

(1) Ing. Geory Lippsmeier, Minimum Cost Housing Construction in El Salvador, (Germany: Institut fur Tropenban, Starnberg, April 1981) 22-26

CASE4.

(1) D.P.Singh, Balbir Singh, "Concrete Skeleton System for Low-cost Houses" India Concrete Journal, May, 1976· 152-157.

(2) S.P.Gupta, D.P.Singh, "Dynamic Testing of a Prefabricated low-cost Housing System" VII Symp. on Earthquake Engineering Vol 1 (India· University of Roorkee, Nov.10-12, 1982) 521-24.

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CONCLUSION

This study provides a basis for a better understanding of SPCSS. There is a historic overview, specific design concerns which were used in developing SPCSS, the performance and limitations of SPCSS and evaluation of some representative systems.

In spite of always being mentioned in some literature, detailed information concerning the application and design data of SPCSS is rare. The previous understanding on SPCSS is mostly general or specific for special task. The basic features of SPCSS seems to have been recognized for a long time, but have never been fully analyzed. This might be one of the reasons that SPCSS seems interesting in proposal but is less successful when put into practice.

Based on existing information, it is found that for better application, a distinction is extremely important between inherent performances and designed performances of SPCSS, but this has been rather neglected. Inherent performances are intrinsic qualities of all SPCSS, no special design or treatment is needed. Designed performances are the performances of a system gained from special design.

The inherent performances are:

(1) SPCSS is a durable structure for houses,

(2) SPCSS houses can use different infill materials and they are easy to be replaced.

(3) SPCSS makes the horizontal extension of the houses easier.

(4) SPCSS allows the free arrangement in elevation.

(5) Except the post-panel system and the system shown in Fig.2.15, SPCSS provides flexibility for layout in first floor and the walls on each floor are independent, The designed performances are:

(1) SPCSS can be a good structure for earthquake, flood and wind resistance,

(2) SPCSS can be a fast erecting component system,

(3) SPCSS can be a very flexible system in layout and expand vertically and horizontally.

To achieve the advantages of designed performances, more attention has to be given to the choice of the infill materials, to the overall housing design, and the design of the skeleton system itself.

The major drawbacks of SPCSS are:

(1) SPCSS lacks flexibility in the design of the over-all shape of houses.

(2) The majority of SPCSS are closed systems, especially those with designed performances. Therefore, the flexibility in application is limited. This means SPCSS is not universally applicable to low-cost housing system, its application is only suitable to certain types of project.

As a small component system, there are four critical points in the design of SPCSS 1) small column grid; 2) thin column and weight reduction techniques; 3) choosing the joint 4) pocket footing.

Technically speaking, SPCSS is a simple structure without much complication or sophisticated details in its design, manufacture and construction. However, SPCSS is still a system with high expectation from its designers but less successes in practice. As a design idea it has become wide spread, but many optimistic proposals have stayed in the realm of theory and many experiments have never been developed beyond a few prototypes.

The late development of SPCSS has shown that the successful applications are characterized by two major factors: one is the organizational aspect of the project, the other is the specific performance demand of the project.

In terms of organization, the successful projects always involved the centralization of manufacture, project planning and management, which led to the extensive use of SPCSS as a guarantee for being low-cost. This factor is important because majority of the SPCSS systems are closed ones, that is why only projects of large scale are economic.

In terms of performance demand, SPCSS is a beneficial system for certain type of houses because of the special functional requirements, for example the Core house, Shell house. The critical point is that SPCSS can simply provide an efficient durable structure with limited finances, the rest of the house can be finished by locally available resources -- cheap materials and unskilled labor. In the future, this house can be easily expanded and upgraded. The special performance demand could also be structural performance including earthquake, flood and wind resistant capacity, but SPCSS is a good structure when this performance are critical. These functions combined with inherent features of SPCSS can make it invaluable in some circumstances. For example, if SPCSS is designed for earthquake resistance as well as fast erection, it would be an efficient system for post-disaster reconstruction. When there is a mass shortage of housing after an earthquake, SPCSS can provide an instant shelter finished by users and can be upgraded afterwards. Also the houses themselves become earthquake resistant in the future.

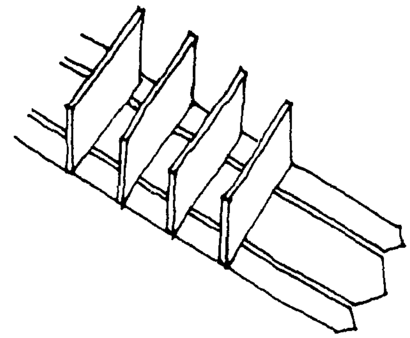
However the question remains, why SPCSS has not been largely accepted as its designer expected?

Some possible reasons are:

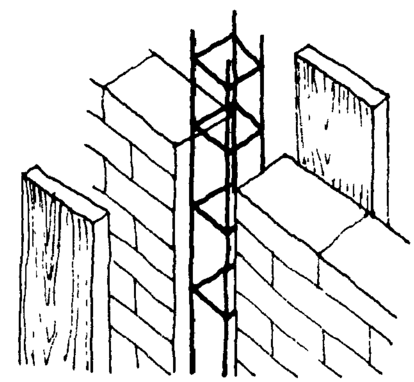
First, SPCSS is mainly suitable for specific conditions as mentioned above, which are largely limited in their application.

Second, the many advantages of SPCSS could be substituted by different systems according to different conditions. These substituting systems may not as good as SPCSS in terms of performance, but they are open systems, more flexible in application than SPCSS which is mainly closed system. These substituting systems are also similar to conventional construction, therefore, are more easily accepted.

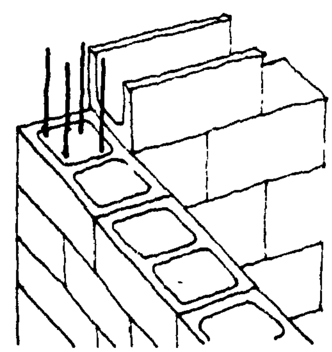
Third, studies once suggested that precast concrete component systems for low-cost housing work mainly for floor members; for the vertical structural part, it can not compete with other kinds of



a series of cross walls can provide enough flexibility



Hollow brick can have a internal pour-on-site skeleton for earthquake resistant



In-situ skeleton combined with precast floor member, has less problem in transportation

Fig.4.1 Examples of substituting system

construction methods* The situation seems still like that. This means, SPCSS may not be economical in general. This could be due to the expensive price of concrete and reinforcement, it could also be structurally uneconomical in terms of material consumption.

**** **** ****

Obviously, contrary to many designers' expectation, SPCSS is not an optimistic structural system for low-cost housing in general. At its best it is a specific system for specific projects. The choice of SPCSS is the result of many factors ---- organization form, housing demand and the availability of resources. For common houses, if other conventional materials, for example burnt brick, concrete block, exist, to use these material or their improved form would be a easier adopted option.

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