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FERROCEMENT HOUSING: TOWARD INTEGRATED HIGH TECHNOLOGY SOLUTIONS

by

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ABSTRACT

After a brief review of the different levels of technologies used in ferrocement housing products, the present paper focuses on the results of a feasibility study recently completed at the University of Michigan where advanced manufacturing techniques were considered for the production of housing units using ferrocement panels. The study suggested that most common housing requirements could be satisfied from a pool of about fifteen standard panel configurations. Box shaped panels were considered for the walls and lintels, while U shaped panels were considered for flooring and roofing. System requirements are described and needed research suggested.

INTRODUCTION

The success of ferrocement in various terrestrial applications including housing has so far been attributed to the ready availability of its components materials, the low level of technology needed for its construction, and the relatively low cost of the final product. However ferrocement offers one often overseen feature, that is, it can be used to achieve products with widely differing levels of quality and cost. High quality can be readily observed in such recent applications as the dome of the Mausoleum Mosque in Amman, Jordan, and the sixty foot long louvres in the Menil museum in Houston. Although the quality of ferrocement products has been proven in many ways, the level of technology involving ferrocement construction is lagging well behind progress in other industries.

Ferrocement has been used in various forms of housing systems requiring various levels of technology. At one end, ferrocement domes were used on a self-help basis as roofs (1) or simply to build entire enclosures called a room, or a house. A higher level of technology was considered in building ferrocement sandwich panels with integrated foam insulation (2,3) ; a higher level of quality is also expected from such products. Highly integrated modular housing units made out primarily of ferrocement have been suggested in various technical publications (4-8) but no real application of such systems is known to the author. Clearly, the higher the degree of integration and sophistication in concept is, the higher the level of possible industrialization is.

Today an extraordinary confluence of new technology and a large market for housing products worldwide can bring about a revolution in the way ferrocement is used. Advanced technology can expand the applications of ferrocement and greatly improve its subjective acceptance by the user as a high quality, high tech., high luxury, durable and cost competitive (not cheap) construction material.

Ferrocement is ready for new technologies and, while housing components of ferrocement can be built using advanced manufacturing techniques, there is need to develop entire housing packages where the ferrocement subsystem is integrated as part of the whole housing system and can occupy a balanced portion of it. Current advances in robotics, computerized manufacturing, machine vision, expert systems and the like allow us to project that such advanced technologies which are already in use in the auto industry can be successfully utilized in the production of manufactured housing systems where ferrocement is the primary structural material.

After a brief review of the different levels of technologies used in ferrocement housing products, the present paper focuses on the results of a feasibility study where advanced manufacturing techniques were considered for the production of single family housing units using ferrocement panels. One of the constraint considered was that the housing system so produced should be of equal if not better quality than standard single family housing units currently found on the U.S. market. The study suggested that most common housing requirements could be satisfied from a pool of about fifteen standard panel configurations. Although the ferrocement subsystem can occupy a wide range of structural and protective functions within the housing unit, it was shown that the same group of panels could be used for the skin (outside bearing walls), the floors, and the roof of the house. In all cases, the connection between various elements was assumed satisfied by bolting. An analysis of the requirements and the potential of such a ferrocement system for housing are described below and related conclusions drawn.

HOUSING CONSTRUCTION: ENGINEERING VISION AND BUYER`S DREAM

It is not uncommon that what seems to be today an engineering vision will likely become common practice a decade from now. In the context of this study, it was anticipated that an expert system would be designed for the use of a ferrocement building system in single family housing construction. Thus, a potential buyer can interact in a friendly relaxed environment with a computer and be brought by the expert system, through questions and answers, to specify the housing requirements he would like to purchase. The system would then provide information on the entire house package. Such information would not only include obvious items like floor plans and elevations, but also isometric views of the house in a particular setting (say rural versus urban), three dimensional views of each room and what is seen from various angles, and other technical details such as types and corresponding numbers of ferrocement panels for factory production and estimated cost. The customer would

then interact with a salesperson to place an order for a house to be delivered within few weeks. Of course this assumes that a site is available and has been readied for housing permit, foundation, sewer and the like. In such a scenario, ferrocement panels could be delivered with their insulation and all electrical jacks installed. Special modular units may be used for bathrooms and be delivered entirely finished.

SYSTEM REQUIREMENTS

Four classes of single family housing systems can be found in the U.S. market: on site construction, modular, panelized, and mobile homes. Their share of the market is described in Fig. 1. In these systems, timber is the primary construction and structural material. Each system may require different levels of technology and integration. Everything else being equal, for on site construction, a low level of technology is sufficient, while a panelized system would require a intermediate level of industrialization, and a modular system would require a high level of industrialization.

Modular units using ferrocement have been considered in the past but their use has been limited. An example was described in an earlier study on prefabricated housing (5). It seemed that the use of a panelized system had a better chance of covering a wider range of applications and was flexible enough to satisfy a larger number of constraints.

Several panel systems using ferrocement are available in the market today. Four different system have been reviewed for this study: a sandwich panel system with integrated foam insulation described by Tatsa et al. (2,3), the Davis system which uses primarily box and U shaped ferrocement panels (9), the Bearingwall System which uses concrete panels with wire fabric reinforcement (10), and the CSM system which uses a sandwich type construction with integrated styrofoam insulation and welded wire fabric reinforcement (11).

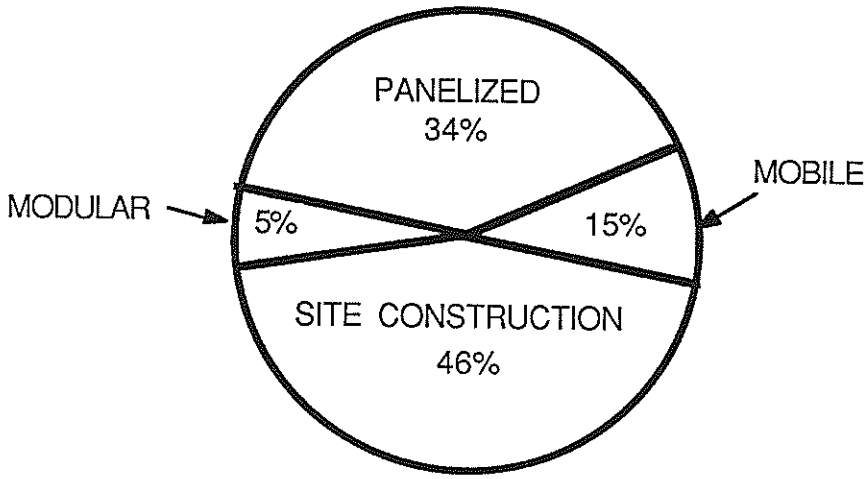


Fig. 1. Share of Single Family Housing in the U.S.

In attempting to develop a new system for this investigation, the following criteria and requirements were considered:

a. light structural components to satisfy easy transportation, erection and handling;
b. small investment capital to insure simplified and movable production facilities of structural panels;
c. flexible units suitable for houses of different sizes and types;
d. versatility of system to allow for different finishing, plumbing, and equipment standards;
e. system suitable for completion and finishing by owner;
f. system suitable for multiple construction units;
g. system flexible to satisfy the most stringent building standards in different countries;
h. system flexible to allow different finishing such as different surface textures and colors;
k. use and availability of local materials;
l. use and availability of labor force on site;
m. and possible production using advanced manufacturing techniques.

Following an extensive evaluation, analysis, and feedback, the system described in this study was arrived at. It should be mentioned that one of the requirements considered was that the panels would be suitable for manufacture by existing industrial robots. This implied that the following functions could be easily performed by robots: parts handling; loading and unloading of materials; cutting and welding; assembly; and spraying, painting, or shotcreting. Thus a highly mechanized production unit with well built steel molds, fast curing capability, automatic crane for moving parts, and flexibility for addition of non-structural parts such as insulation and electrical was assumed possible.

RESULTS OF FEASIBILITY STUDY

A feasibility study was undertaken to evaluate the use of high technology manufacturing techniques for the construction of single family housing units utilizing ferrocement as a primary structural material. As mentioned earlier, a ferrocement panel system satisfied all the important constraints of the problem and was selected for a detailed evaluation. The study was divided into four main parts, namely: construction method, architectural design, structural analysis and design, and fabrication. The four parts allowed interactive feedback, until an acceptable solution satisfying most of the requirements stated above was arrived at.

The construction method included solutions related to transportation, erection, site assembly, integration of electrical, plumbing, and heating/air conditioning units, connection to the foundation or basement walls, hoisting requirements, on site equipment needed and cost evaluation.

The architectural design dealt primarily with the development of an acceptable ferrocement system for industrialized housing (which ended up being a panel system). It dealt with the development of standard panels, modular coordination, architectural layout, types of connections, aesthetics, weight, length and transportation con-

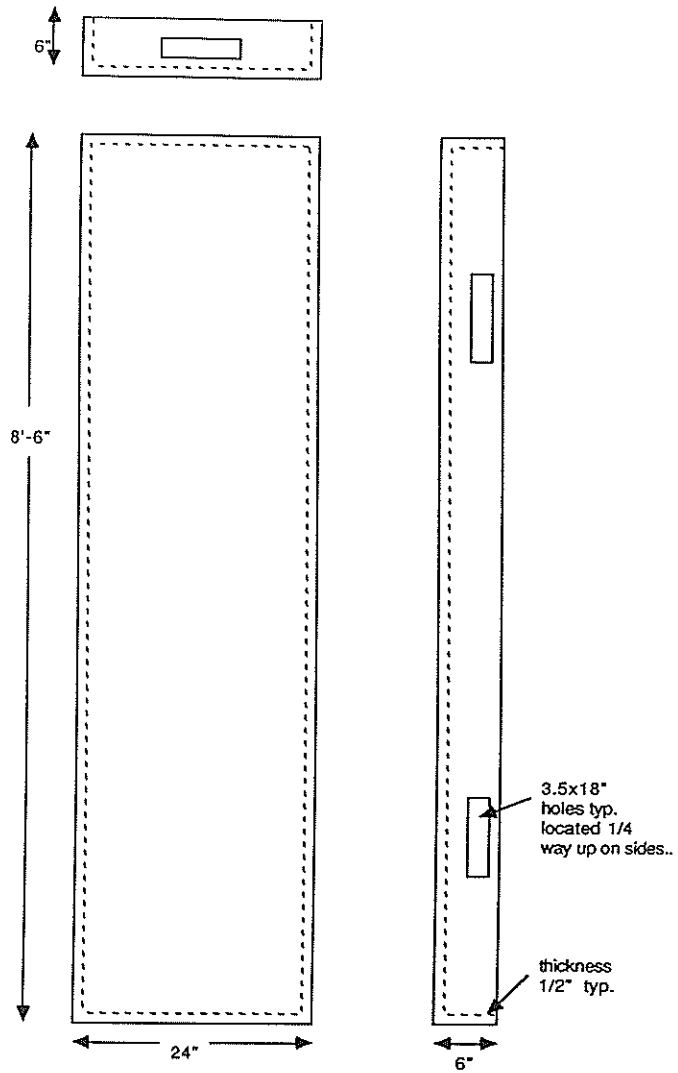


Fig. 2. TYPICAL WALL PANEL

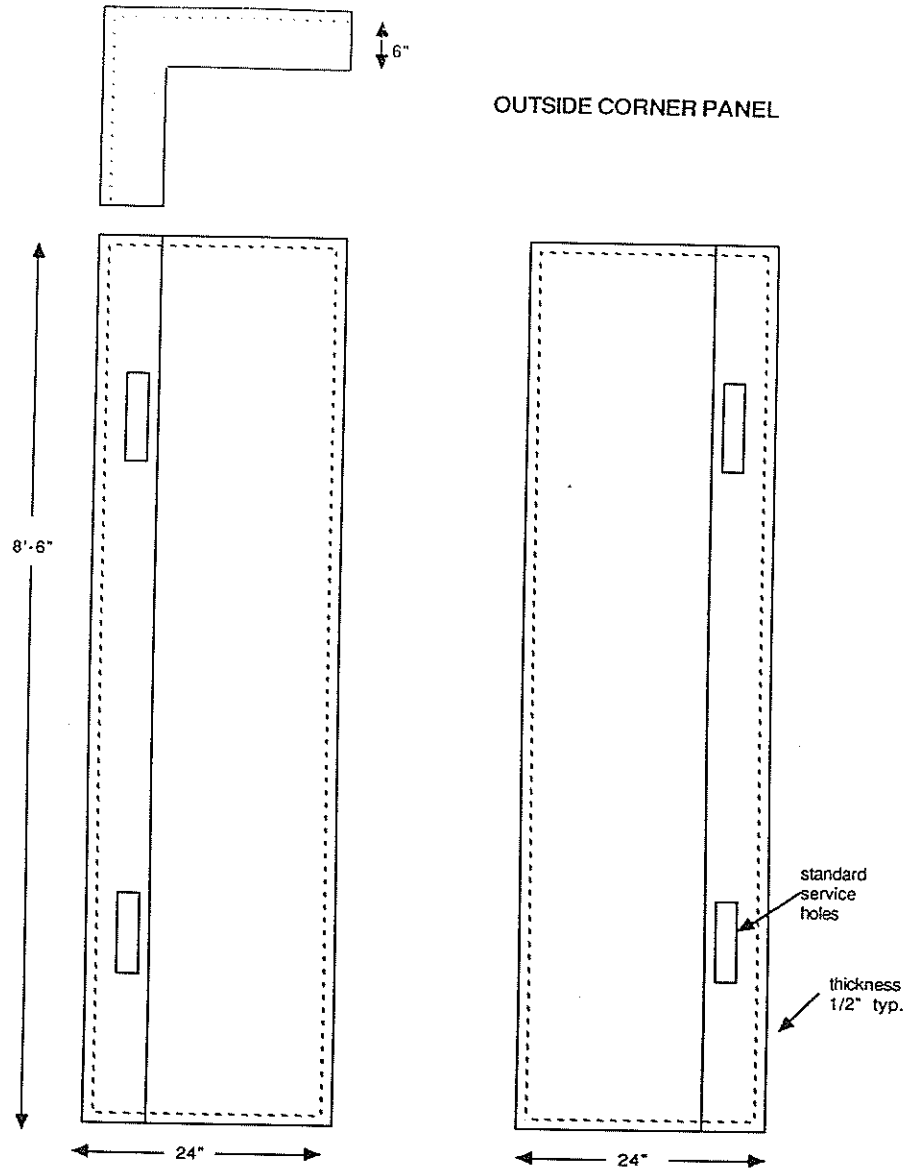


Fig. 3. OUTSIDE CORNER PANEL

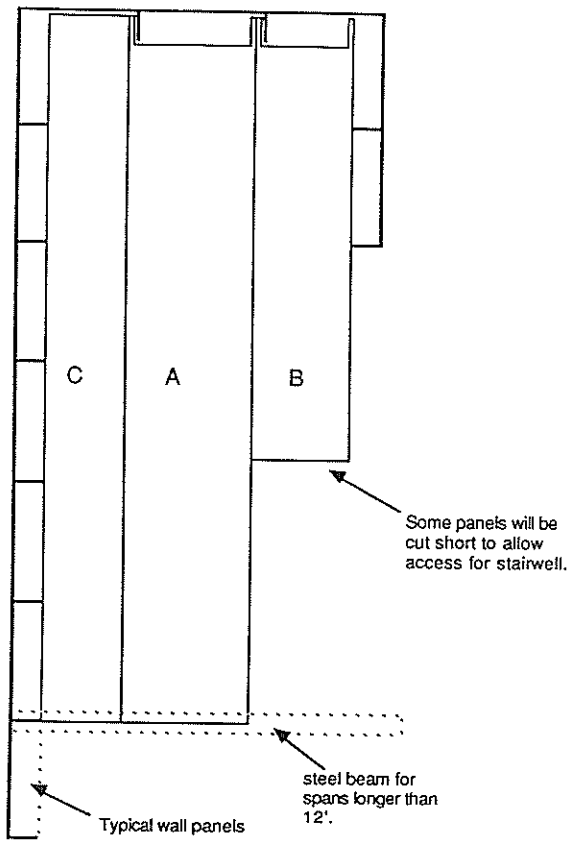


Fig. 4. TYPICAL FLOOR LAYOUT

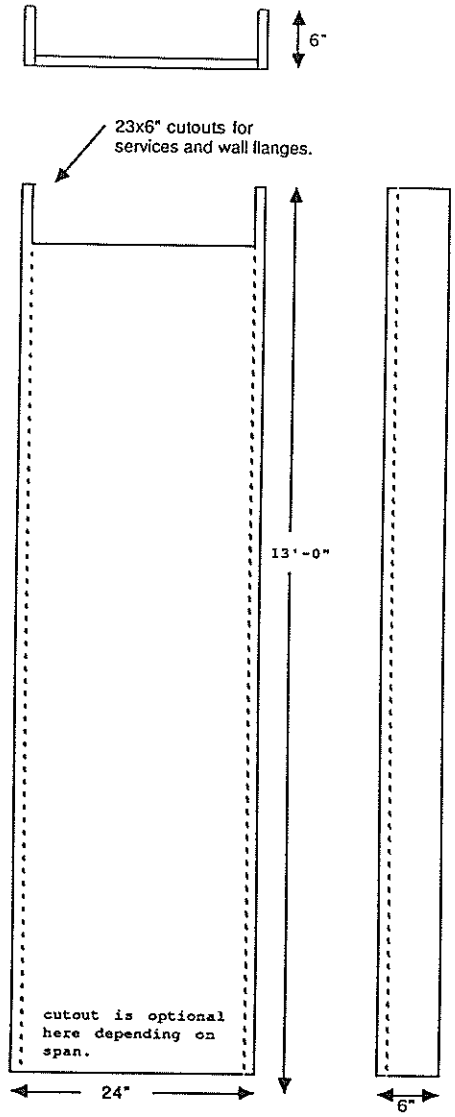


Fig. 5. ROOF/CEILING PANEL

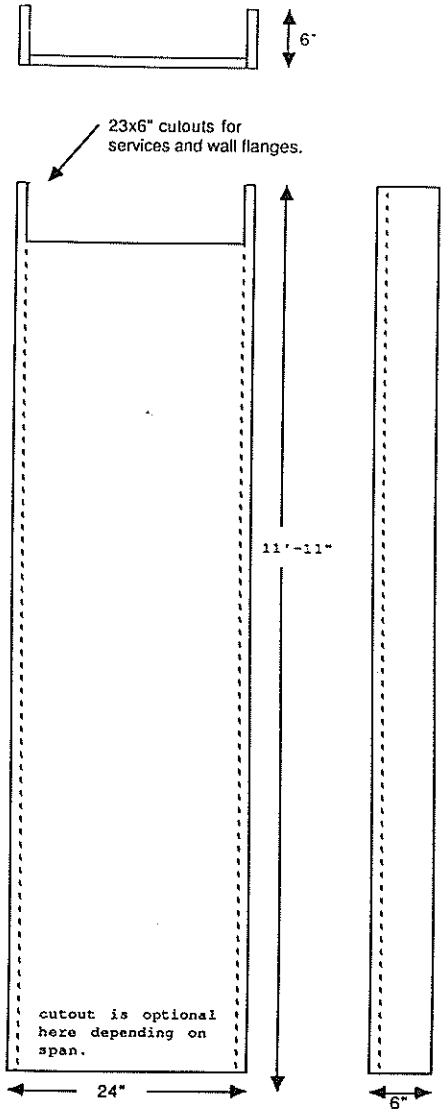
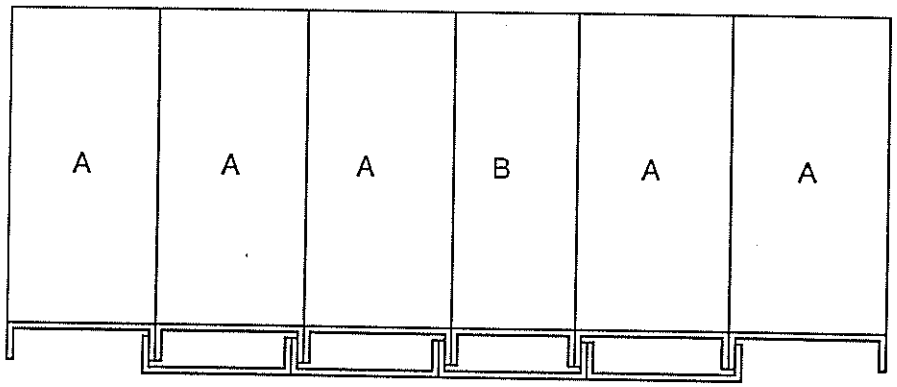


Fig. 6. FLOOR PANEL A



This diagram shows the arrangement used for the roof panels. Only one panel B is used for each side.

Fig. 7. Typical Arrangement of Roof Panels

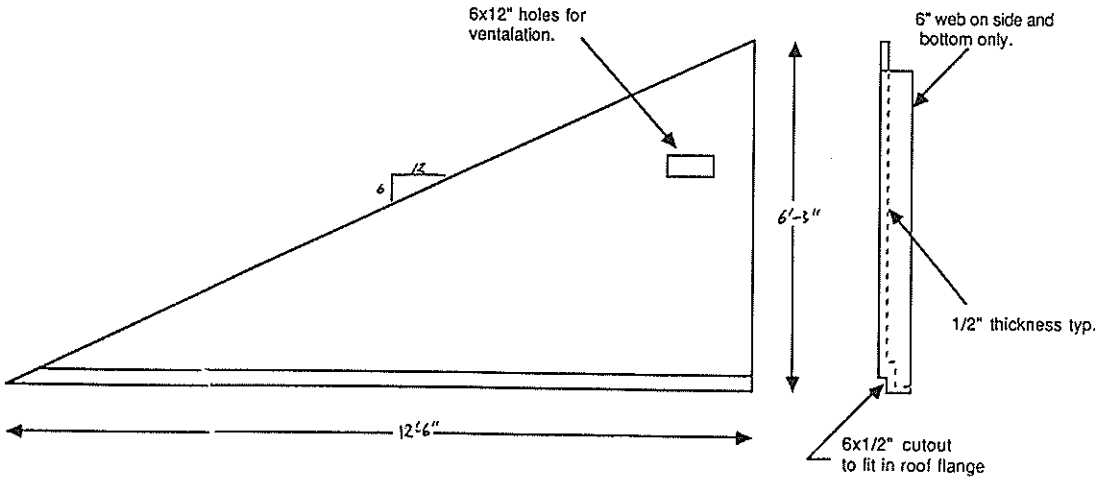


Fig. 8. Typical Filler Panel

the roof of the house (in this example two filler panels are needed per side).

For the reinforcement of both wall and floor panels, a minimum of two layers of wire mesh was considered combined with a No. 3 reinforcing bar placed along the panel edges. Various reinforcing schemes (type and size of mesh, number of layers, etc...) were developed for various combinations of spans and live loads. In all, the following ferrocement components were developed, each offering potentially different lengths or spans: two types of wall panels and two corner wall panels, lintel elements having same basic dimensions and different lengths (Fig. 9), three types of floor panels, two types of roof panels, and triangular filler panels for the sides of the roof. A photograph of a part scale model using the system developed is shown in Fig. 10

The study showed that the ferrocement system developed is a technically feasible system suitable for a highly industrialized production facility at a competitive cost. It also indicated that the problem of connection between ferrocement elements is the least documented in the technical literature and should receive high priority in future research. Connections allowing the use of bolts to assemble ferrocement elements produced with high precision surfaces can save a lot of time and money if proven structurally acceptable.

CONCLUDING REMARKS

The integrated wall panel housing system described in this study requires only one thorough technical investigation before it can be adopted with confidence in practice, namely, a comprehensive evaluation of joints and jointing techniques between ferrocement elements. All other technical problems can be solved using current state of knowledge and current levels of technology. On the other hand, better knowledge and advanced technology of production are of no practical use without the development of consistent and rational building codes and guidelines covering ferrocement as a structural material. The guide recently published by ACI Committee 549 on the Design, Construction and Repair of Ferrocement provides acceptance criteria that can be implemented in building codes (12), but represents only a first step.

Once these technical needs are satisfied and obstacles overcome, it should be pointed out that a high technology solution for the housing problem using ferrocement as a basic structural material is only one of the possible advantages of integration and systems approach. Any real undertaking would require careful planning, effective organization, financial backing and strong marketing. Marketing is particularly needed to educate the engineering profession first and the public next, to eradicate the misconception that ferrocement provides solely "cheap" "low cost" solutions for housing. Next to wood, ferrocement is today the most versatile building material for housing, since it can be effectively used in all structural and non structural components.

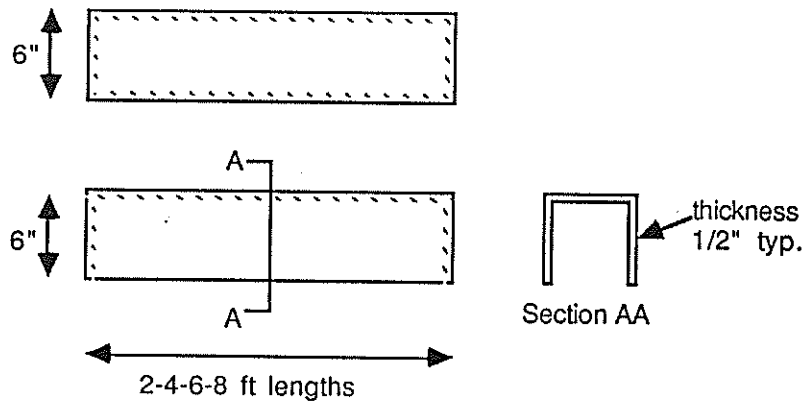


Fig. 9. Typical Lintel Section

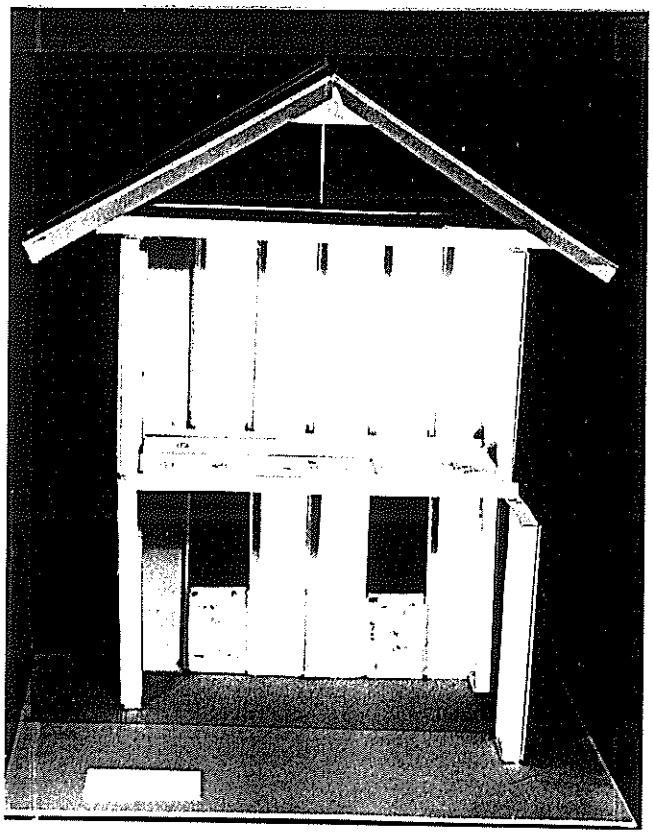


Fig. 10. Scale Model

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