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INDUSTRIALIZED CONSTRUCTION — A COMMENTARY

BY

Colin H. Davidson

Synopsis: Industrialization of building affects each member of the building industry differently - consequently there is little agreement within the industry as to its exact nature. Industrialization concerns processes, mechanization, organization and continuity; related to industrialization are the concepts "system" and "environment"; thanks to the systems approach, it is possible to bring industrialization into the building industry. The nature of the building products changes radically, affecting the scope for continuity of production; marketing and contractual procedures are necessarily affected, leading to changes in the roles of the participants (i.e. technological change is accompanied by organizational change). In this connection, it is necessary, however, to distinguish between "need" and "effective demand" - most system sponsors are extraordinarily lax about market studies. Introducing the performance concept increases the scope for innovation, but raises major difficulties of interpretation, demanding new skills within the industry.

Keywords: construction; environments; industrialized buildings; market research; performance; prefabrication; structures.

2 industrialized concrete construction

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INTRODUCTION

The industrialization of building affects each person in the total building process; in the struggle for survival in our industry - as it moves towards a more "industrial" method of operation, each one of us constructs an image of that future that reflects his own present-day view point; he defines the main characteristics of that future in terms of his own priorities.

The papers that form this group aptly illustrate this divergence. Each author, responding to the challenge to view the immediate past, the present and the future of industrialization, brings out points that are pertinent to his own experience; in so doing, he also reveals his own preconceptions, and his own scale of values.

The purpose of these notes is to suggest some generalities about the industrialization of building, that will enable the other papers to be viewed as parts of a whole, rather than as apparently conflicting statements about an ill defined subject.

DEFINITIONS

We must start by being clear about some of the terms we use; here are some definitions and explanations.

INDUSTRIALIZATION is (Z): a productive method, based on mechanized and/or organized processes of a repetitive character requiring continuity... Note in this definition the two facets: a) methods and processes; b) repetition and continuity. I do not endorse the use of the term "industrialized" as applied to building - and as used in the title of this group of papers - since it would seem to imply that there is some other kind of building which is not industrialized. Non industrialized building does not exist; even the most traditional forms of construction use some industrially made products (bricks, nails, glass and the like). Indeed, these products are mass-produced. What we are concerned with, therefore, is an evolutionary process; when we refer to industrialization in building, we mean "increasing the amount of industrialization ..."

Now, the industrially made products of traditional building are small and simple. They can be used in almost any kind of building - in other words, they can be mass-marketed into the traditional building industry,

industrialized construction—a commentary 3

with all the variety that it contains. To assemble them, however, many manual (i.e. non-industrial) operations are required. Therefore, when we call for more industrialization, it is likely that we are also calling for the industrial manufacture of more complex products - designed to be assembled industrially. As we will see, this soon becomes a major departure from traditional building.

SYSTEMS: As soon as industrialization is discussed, the concept of systems is raised. A system is (2) a set of objects with relationships between them and between their attributes... Note again two significant facets: a) set of objects; b) relationships.

ENVIRONMENT: Any discussion of systems immediately brings up the concept of environment. The environment of a system is (3): those objects outside the system (i) which are influenced by a change in the system or (ii) a change in which influences the system.

In building terms, the building industry is a system. Its members are the "objects", the network of contracts and communications between them are the "relationships". The environment of the building industry system includes political, social and economic interests of many sorts.

THE SYSTEMS APPROACH

If we now associate these two concepts - evolutionary industrialization taking place within the building industry system, we can begin to understand why the problems are complex and why it is so difficult for one or two members of the industry to make a significant impact on the degree of "industrialization" in building, when they "go it alone".

Traditional building products, I stated, are often mass-produced, but nearly always being simple - require manual assembly processes. Industrialization, I have also suggested, implies a change in this situation, leaning to the use of more complex products where the "complexity" is specifically aimed at simplifying the assembly processes. This, in itself, involves some major industrial design type activities; in addition, there is a production consideration that must not be overlooked: introducing new, easy to assemble products would be pointless if these more complex products - though easy to assemble - had to be hand made !

Now, there is a relationship between the size (or complexity) of a product, the variety of situations in which it can be used and the number of models that must be on offer (4). For a given variety: bigger products need more models; for a given number of models, bigger products mean less variety, etc. From this, we can immediately deduce that the call for industrialization and its more complex products, interferes with the present delicate balance between the kind of industrialized product being made for building and the kind of variety that the building industry traditionally demands.

In other words, a technological change - the limits of which can be controlled by one or two members of the building industry, immediately

4 industrialized concrete construction

has far reaching consequences. To produce complex products industrially, i.e. to offer a reasonably restricted number of models, implies that the number of situations in which they are used is appropriately restricted; this, in turn, implies that the design of the building is somehow adjusted to these products, and also the decisions to purchase the buildings are affected. We see that the technological change has repercussions that reach right through the total building process. Once we remember that the building industry is a system, this becomes less surprising; the consequences are difficult to deal with, even if they are less surprising.

In effect, this is an example, one example, but an important one - of how any partial change of building practice immediately produces a kind of chain reaction. A good model of the building industry would be a playground climbing net; change the position of one climber and all the others have to readjust their positions as the stresses redistribute themselves; indeed, the support ropes all change directions too, interacting differently with the supports themselves.

When the systems approach is discussed, one is recognizing that the building industry is a system and also recognizing that any one change should be accompanied by a systematic prediction of, and positive action on, the consequences elsewhere in the system. When systems building is discussed, one is referring to situations in which a limited systems approach is adopted, in which "building systems" (named ventures often of a proprietary nature) are proposed; these "building systems" are still sub-systems of the building industry as a system; one hopes that the sub-systems in question control enough factors to be able to make a success of the individual changes - industrial changes - within it (5). Building systems often run into trouble, as we all too well know - usually it is because of some unhealthy relationship between them and their environment (remember that the environment of a building system is the building industry and its environment). The problem area is usually marketing.

In the area of marketing, many building system sponsors behave with extraordinary naivete conducting only the most generalized market studies. It is essential to start from the right premise and distinguish between the "need" and "effective demand" (6); "need" is a social measure of shortage (e.g. 26 Million dwellings in the U.S.A. between 1968 and 1978, 365,000 dwellings per annum in the U.K. in the '60s); "effective demand" is a statement of the numbers of buildings for which contracts can be placed with the building industry. Effective demand is often very different from need; money can be made or lost against effective demand; as for need - I suppose only politicians or sociologists careers can be built on it!

In short, the systems approach to industrialization requires that markets be studied thoroughly - as part of the systems analysis of the environment of the proposed system.

PERFORMANCE

Any discussion of industrialization brings up the concept of performance; supposedly the description of "effective demand" in performance terms (i.e. without any reference to the nature of the physical solution) (7) opens the door for innovation. This is undoubtedly true up to a point, since performance terminology avoids certain descriptive constraints couched in terms of such and such a material, however we must be extremely cautious for several reasons; notably a) it is extremely difficult to write good performance specifications; indeed, it is at present impossible to write performance specifications without some allusion to the nature of the physical solution, and b) it is not yet possible to deduce the physical solution from a performance specification (we can postulate a solution and verify its performance characteristics against the performance criteria as specified) (8).

SKILLS

To proceed in performance terms implies a new set of design skills and design procedures; no longer is it possible (for technological and administrative reasons) for the design process to proceed in the traditional one-way multi-step way, starting with the design brief and finishing with site construction. Instead, it will proceed on several fronts, simultaneously, with systematic user-requirements studies leading to performance statements, with product designs accompanied by systematic assembly studies, with industrial engineering proposals leading to the design of new methods and new equipment. In other words, these will be new roles requiring new skills and new relationships; these skills will - at one and the same time - require a mixture of a systems engineering ability to view a whole problem area, and a scientist's skills in isolating part of that problem and finding new solutions with predictable behavior.

INDUSTRY STRUCTURE

To exercise these roles will require, as I have mentioned, new relationships between the participants; however, I do not believe that the giant building corporation is the best framework within which this work can take place. The traditional building industry has many merits that should not be overlooked: for example, its versatility: the entrepreneurial character of its members, etc.(9). Some way must be found to minimize the short comings of the industry; however, I suggest that its present dispersion and discontinuity should be replaced by coordinated management functions such as systematic communications, restructured responsibilities and so on. Note that coordinated management is not dependant on commercial integration of the various bodies. It is perfectly possible to have coordination between economically and commercially independent bodies; it is more difficult to have coordination when a state of potential conflict of interests exists.

6 industrialized concrete construction

CONCLUSION

To summarize, we have defined industrialization in terms of processes and systems in terms of relationships. To increase the amount of industrialization, we may have to change the nature of the products with which we build, implying a new attitude to the market for our services. The performance concept is one aspect of a change in defining the relationship between user requirements and the physical solution, but it immediately has repercussions on the roles of the various participants in the design process. However, the ensuing structural changes in the industry need not lead to the creation of giant building corporations; instead, management tools, (communications in particular) can prepare the traditional building industry for the systems approach that must accompany industrialization.

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INDUSTRIALIZED CONCRETE CONSTRUCTION FOR HUD

BY

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Synopsis: This account of the Department of Housing and Urban Development's (HUD) role in industrialized concrete construction is prefaced with a summary of the European experience, begun early in the 20th Century. Conditions existing in Europe after World War II, similar to some conditions in this country today, encouraged industrialized housing. Several systems were introduced into the U. S. in the 1960's and development of additional systems was encouraged by HUD's "Operation Breakthrough." The Federal Housing Administration (FHA) was called upon to review many of these systems for acceptance by way of Structural Engineering Bulletins.

The gas explosion and progressive collapse of the Ronan Point Building in London, England in 1968 greatly affected the precast concrete industry. Design codes had treated continuity of prefabricated buildings in a very cursory manner and few engineers seriously considered it a basic design feature.

HUD, in 1969, began a concerted effort to develop criteria so that people living in buildings constructed under its programs would be protected from similar failures. Provisions were first contained in Structural Engineering Bulletins issued to several concrete systems sponsors. HUD then began development of a design handbook to inform its field offices of the potential problem and means for solution.

Under initial promotion by HUD, the American Concrete Institute and Prestressed Concrete Institute established special committees to develop criteria for design and construction of buildings to resist progressive collapse. HUD contracted with the National Bureau of Standards for research on abnormal loadings and buildings systems that did not inherently possess adequate continuity and ductility.

Systems acceptable for use under HUD housing programs are listed, with number of units, heights of buildings, construction costs and types of HUD programs tabulated for each system.

The emphasis of the paper is on multifamily, highrise concrete construction; single-family residential construction is not addressed.

Keywords: bearing walls; collapse; concrete construction; concrete panels; continuity (structural); failure; high-rise buildings; industrialized buildings; loads (forces); masonry; precast concrete; prefabrication; project planning; residential buildings; standards; structural analysis; structural design.

8 industrialized concrete construction

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INTRODUCTION

The Federal Housing Administration (FHA), which is now a part of the U. S. Department of Housing and Urban Development (HUD), has been involved in the evaluation and acceptance of manufactured and pre-fabricated housing since 1946. Special Engineering Bulletins were issued to cover the structural features of what was then considered innovative housing construction.

It was not until the 1960's however, that industrialized concrete systems for multistory residential structures became viable in the United States. With very little background or pertinent codes to use in its evaluation, FHA was requested to accept this type of construction through the issuance of Structural Engineering Bulletins. Fortunately, data from several decades of European experience was available.

The evolution of industrialized concrete construction in the U. S. is similar in many ways to that in Europe. Some of the same basic reasons for industrialization in housing in this country existed years ago in Europe. Therefore an account of the early European Experience is in order.

EUROPEAN EXPERIENCE

Industrialized concrete construction or more specifically panelized and modular precast concrete systems are generally considered to be of European origin. Records indicate that a prefabricated concrete bearing wall system was used as early as 1892 by a French firm, Constructions Edmund Coignet, for a casino building (1). Concrete Limited of England began to manufacture precast concrete plank in 1919, but a precast system for an entire building was not developed until some years later. Several large panel systems were then developed in Europe and the United States during the 1920's. Most of these did not survive (2). Inadequate handling capacity of equipment was a prime handicap (3), and these systems could not compete economically with conventional construction.

Major developments in prefabricated concrete system building occurred in Europe after World War II. Many countries suffered from a severe housing shortage, especially for low-income groups. There was also a lack of skilled building labor. Industrialization, it was believed, could bring about a significant decrease in the cost of residential construction (4).

The evolution of industrialized systems in Europe occurred in three stages (4). The first stage, during the late 1940's and 1950's, supplemented traditional construction methods and attempted to raise the level of technology and scale of production. Progress continued as national and local authorities stepped in to assure continuity of demand and to support research and production. During the second stage (late 1950's and early 1960's) many systems that were neither competitive nor acceptable to consumers were weeded out. Successful systems were given additional support by the government; some were consolidated or refined. The third stage occurred during the late 1960's when a concerted effort was made to apply scientific methods to engineering design, production, distribution, and erection with the intention of significantly lowering cost below that of conventional construction.

It has been said that the much needed increase in housing production could not have been achieved with the existing labor force by using conventional building methods (5). Industrialization could reduce on-site labor by as much as 30 to 50%, and erection time could be greatly reduced. Essential features of industrialized building systems are mechanization and attainment of a rhythm of production. Combined they result in continuity and evenness of output. Labor must be reorganized in separate, distinct phases and different labor and trade specialities must be established. Industrialization therefore should cause development of more specialized on-site labor forces. Other end results may be more efficient use of materials, a shorter construction cycle, and a less seasonal industry (1).

What has been the impact of industrialization on residential construction in Europe? In recent years the East European countries generally exhibited a greater percentage of industrialized residential construction than did West European countries (6):

German Democratic Republic - 90%
Hungary - 69%
Czechoslovakia - 69%
USSR - 57%
Bulgaria - 33%

United Kingdom - 38%
Denmark - 35%
Netherlands - 30% (1968)
Norway - 28%
France - 21%

In countries where highly industrialized concrete systems were developed, the skill-mix of the construction industry changed considerably. The transfer of functions from site to factory and the development of new machinery caused a decline in some traditional crafts. While the importance of certain traditional manual craft skills declined, machine oriented skills increased. The on-site manual labor requirements, especially of concrete workers, greatly decreased and new off-site techniques of heating, casting, and finishing, caused many workers'

10 industrialized concrete construction

tasks to become more specialized. The overall quality of building labor force skills, however, was not substantially lowered by industrialization, but the number of on-site workers was reduced. Studies show that in most European countries the on-site labor force was reduced by at least 50%. Box-type systems in the USSR showed an even greater reduction, as high as 80%.

The translation of man-hour savings into net building cost savings is difficult. Some European countries have claimed a clear cost advantage for large panel prefabricated systems over conventional construction, on the order of 10 to 20%. Several other countries, especially with highrise construction, claim a cost advantage in the range of 5 to 15% (6).

A secondary aspect of cost is associated with completion time. On-site completion time has been markedly reduced in most European countries. Such reduction saves capital costs during the construction period and advances the time for income realization.

EARLY U.S. EXPERIENCE

Industrialized concrete construction has been used in the United States since the early 1900's. But not until the late 1960's was any system developed which overcame the many constraints of residential construction while providing aesthetically and functionally flexible buildings which were also economically feasible. High labor and material costs and a strong demand for residential units have, it appears, finally changed the climate in favor of industrialized systems.

One system developed in the early 1960's and still actively used in constructing residential units was that developed by Sepp Firnkas, Structural Engineer, of Boston. This system is very similar to many European crosswall panel systems except that extruded prestressed floor slabs are used and vertical wall panels are post-tensioned to ensure continuity. For several years prefabricated concrete systems were used only for buildings up to four or five stories, but in the last five years many buildings have been constructed in the 15 to 24-story range.

Habitat '67 in Canada piqued the interest of the U.S. housing industry. It was an exciting architectural utilization of prefabricated modules for residential construction; an escape from the typical staid cracker-box type of system. About that same time, H. B. Zachry Company developed a box-module system in San Antonio, Texas. A crash program involving the use of a checkerboard pattern of modules for the 21-story, 500 room Hilton Palacio del Rio was required. Construction had to be completed in nine months so the hotel could be ready for occupancy by April 1968 for the opening of the Hemisfair. The first module was cast on August 15, 1967; erection began on November 10; and the final module was in place on December 20. After completion of the hotel, several two-story apartment buildings were constructed for HUD (7). Many motel/hotel units have also been constructed using this same approach.

Early HUD concern over insufficient housing is evidenced by a 1967 demonstration grant awarded to Illinois Institute of Technology Research Institute (7). This program was conducted as part of a search for means of lowering costs of multistory housing for low income families in response to the need for six million such housing units.

Included in the study was an extensive survey of industrialized building methods in use throughout the world. The system selected for study as best conforming to the then current posture of the U.S. construction industry, trade unions and building codes was a three-dimensional, open-top, concrete box module similar in concept to the H. B. Zachry System. A ten-story building with 78 apartments was modeled and several box unit models were tested. A cost study predicted that the building would be 6% less expensive than a conventional one. With volume production, it was estimated that savings could be increased to as much as 18%. Part of this savings (3%) would result from reduced interest on borrowed construction funds, because of a 40% decrease in construction time.

U.S. NATIONAL HOUSING PICTURE

Some two-thirds of the population in 1968 was concentrated in the nation's 228 metropolitan areas. Between 1950 and 1960, 88% of the U.S. population growth occurred in these areas, and estimates are that the total population will grow from 200 million in 1960 to 260 million by 1985. The addition of 60 million people will mean 20 million new households needing residence, most of this in urban areas (8).

In 1968, President Johnson's message to Congress called for a new direction in the housing program: 20 million private housing starts plus 6 million constructed or rehabilitated, partially subsidized units over the next 10 years. This meant that an average of 2.6 million private housing units per year was a necessity with an industry that had not supplied over 1.5 million units per year at any time in the preceding 10 years. It appeared that industrialization was the only solution to the housing shortage (9).

INDUSTRIALIZED CONCRETE SYSTEMS AND HUD

The need for housing was clearly evident as previously expressed. The 1968 National Housing Act had directed HUD to evaluate new materials and methods and to accept those that proved technically suitable for HUD/FHA programs. Of significance was the continuation of housing systems acceptance, begun in 1946, through the use of Structural Engineering Bulletins (SEB's). Manufactured housing systems proposed for use under FHA programs required review and acceptance of the structural features by Central Office. Items not covered specifically in the FHA Minimum Property Standards were required to be described in the SEB's.

12 industrialized concrete construction

Some European systems developers, realizing the potential of the U.S. housing market, began to form affiliations in this country. The first system submitted to HUD was the Cebus System, sponsored by Laurel Concrete Products, Inc. of Maryland and designed by Tadjer and Cohen, Maryland structural engineers. Initial submittal was in January 1968. Design was based on a June 1966 French document "Joint Directives for the Acceptance of Building Systems with Large and Heavy Panels," by Cahiers du Centre Scientifique et Technique du Batiment, as translated in August 1966 by Union Europeenne Pour L 'Agrement Techniques Dans La Construction. This document provided for peripheral and transverse horizontal tie beams to develop diaphragm action. Structural Engineering Bulletin No. 455, based on the above requirements, was issued by HUD on May 29, 1968. The Cebus System is basically a precast concrete one-way floor system supported by precast concrete panel crosswalls. Tie beams are formed in the plane of the floor slabs by reinforcement set in cast-in place concrete joints. Reinforcing steel loops extend from the ends of abutting floor plank and are laced together by continuous reinforcing bars.

Concrete Limited of England submitted data on the Bison System in April 1968 through its U.S. representative. However, complete submission of structural data confirming the integrity of the system was not made until 1969. The Bison System uses prestressed one-way concrete floor plank with supporting crosswalls similar to the Cebus system. Processing for an SEB was however proceeding normally until information was received in this country concerning the failure of a precast system in England. Several months passed before complete data concerning the explosion in an apartment building called Ronan Point filtered through to the U.S.

RONAN POINT DISASTER AND BRITISH STANDARDS

On Thursday, May 16, 1968 at 5:45 a.m. a gas explosion on the 18th floor of a 22-story apartment building in Canning Town, London, England, rocked the prefabricated concrete industry. The explosion triggered the collapse of an entire corner of the Ronan Point building and demonstrated the lack of attention paid to structural continuity in some buildings.

The British reacted very swiftly, spurred by public pressure and political necessity to investigate the cause of this disaster. The Ministry of Housing and Local Government conducted a public inquiry. Public hearings started the 30th of May, 1968 and ended August 2, 1968. The "Report of Inquiry into the Collapse of Flats at Ronan Point, Canning Town" was printed in October 1968. This report includes several recommendations concerning the use of gas in residential structures, inspection of existing similar construction, and the design and construction of highrise buildings (10).

The Ministry of Housing and Local Government then issued a follow-up three page document, "Standards to Avoid Progressive Collapse - Large Panel Construction," dated November 15, 1968. Two methods to avoid progressive collapse are delineated: "Method A - By providing

alternative paths of support to carry the load, assuming the removal of a critical section of the loadbearing walls; or Method B - By providing a form of construction of such stiffness and continuity as to ensure the stability of the building against forces liable to damage the load supporting members." An equivalent static pressure of 5 psi was specified, and minimum tie forces were derived to provide resistance to this design pressure.

It is interesting to note that in February of 1969, amendments to the "International Recommendations for the Design and Construction of Large-Panel Structures" were issued by the Comité Européen du Béton (CEB). It emphasized "how absolutely necessary it is to achieve effective interconnexion of the various components in order to obviate any tendency for the structure to behave like a house of cards; and to organize it accordingly. In this respect, it appears to be of prime importance to install steel ties which are mechanically continuous, some of which encircle the structure while others interconnect the walls or facades on opposite sides and involve all the vertical panels." Their recommendations also included two methods of analysis to design for an explosion hazard; 1) Provide an "open configuration" arrangement of panels to contain wide gaps filled with walls of no appreciable strength (valve walls); or 2) The "alternative path" method considering the destruction of a loadbearing element and providing a second line of defense formed by surviving elements (ties, wall panels and floor panels).

Objections to the various British recommendations were voiced by many sources. Although the CEB recommendations stressed the same points as those from the United Kingdom, only the British documents were criticized.

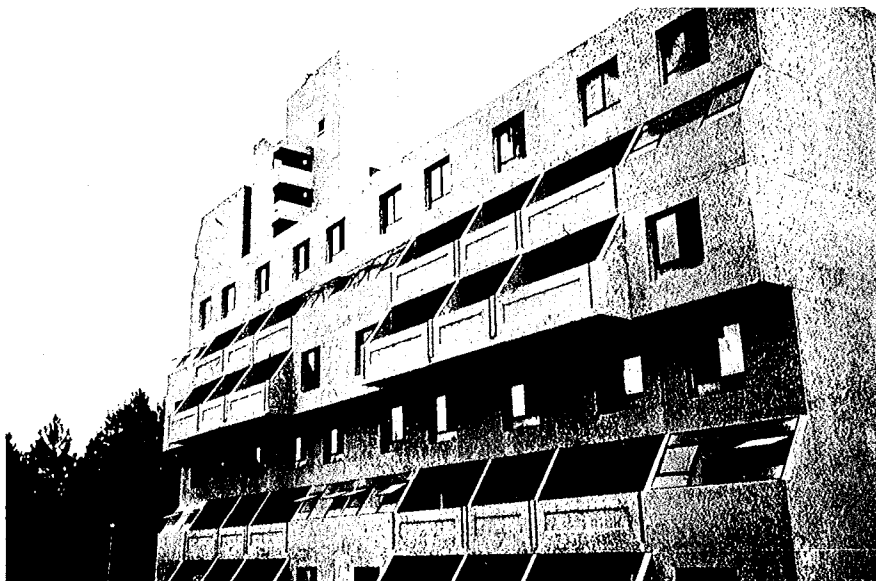
CONCRETE SYSTEMS AND HUD - CONTINUED

In September 1968, a U.S. representative of Constructions Edmund Coignet, a French firm, submitted data on the Coignet System, a method similar to the Cebus system. This system also provided tie beams as required by the 1966 French document. HUD issued SEB No. 482, dated 10/28/68, covering construction of buildings up to 24 stories in height.

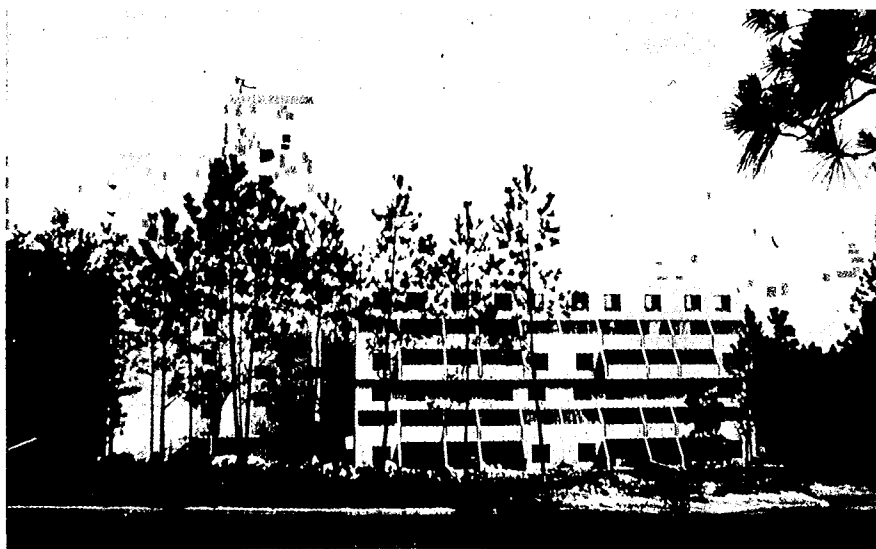
Balency MBM Associated in Milan, Italy also contacted HUD September 1968 requesting information on application for acceptance under the 1968 Housing Act. Their consultant in New York initiated a request for processing under a joint venture: Balency-MBM-US Corporation. Building Systems International, Inc. was then organized in 1969 to develop the Balency System for use on the Macon, Georgia Breakthrough site. Processing for an SEB was not completed.

Because of the Ronan Point collapse and ensuing investigations, HUD in February 1969 requested comment on the November 1968 British Standards from the holders of the two existing Structural Engineering Bulletins (Cebus and Coignet) and from the proponent of the Bison System. Each replied explaining their interpretation and considered

14 industrialized concrete construction



Balency System, Macon, Ga., HUD Operation Breakthrough



Balency System, Macon, Ga., 12 story highrise and 6 story medium rise, HUD Operation Breakthrough

compliance with the regulation. This and other correspondence seemed to indicate a general lack of consensus among prominent structural engineers as to the probability of either progressive collapse or abnormal loadings. However, structural engineers at HUD, involved in acceptance of housing systems under Federal Housing Administration programs, considered the British recommendations to be valid and took steps to implement them in the U.S. They also thought that the "Alternate Path" method of analysis was essential, but to achieve an alternate path one needed to provide vertical continuity in all bearing walls to support floor loads and upper wall panels if a wall panel were destroyed by an abnormal load.

In June 1969 a fifth European panelized system requested HUD acceptance via an SEB. Dr. Alan Foster of Camus (Gt. Britain) Ltd. visited the HUD Central Office in Washington, D. C. and presented his documentation. Shortly afterward, structural calculations and details for a prototype 20-story building were received, but these were not in compliance with the British requirements on Prevention of Progressive Collapse. Revisions, however, were proposed and substantiating calculations were being prepared.

Tracoba, sponsored by Industrialized Building Systems, Inc. of New York, was the sixth European panelized concrete system to request a review by HUD. Documents were received in August 1969, but since the first submittal was incomplete, acceptance was delayed.

HUD PERSONNEL TRAVEL TO EUROPE

With two European industrialized systems found acceptable by HUD, four others under consideration, and further applications expected, it was considered advisable that HUD personnel visit Europe to learn of concrete panel systems firsthand. A two-man team - an architect and a structural engineer - visited England from September 8 through 27, 1969. They visited government agencies, trade and professional associations, systems builders' design offices and factories, research stations, new towns and construction sites.

Visits to manufacturing plants afforded excellent instruction in production methods, shop practice, assembly line techniques, quality control, transportation and storage. Site inspection covered erection procedures, joint reinforcement, grouting, flashing, and waterproofing. Interface with on-site constructed elements such as foundations, utilities, and service systems was observed. Completed and occupied projects were visited, and the occupants were briefly interviewed in some instances. The trip included a separate, one-day visit to France by each team member to inspect factory methods and site installations.

The systems studied during visits to factories and sites in England and France were:

- 1) Balency (Thamesmead Project)
- 2) Bison (Concrete Limited)
- 3) Camus (Camus, Gt. Britain, Limited)

16 industrialized concrete construction

- 4) Coignet (Construction Edmund Coignet)
- 5) Laing (John Laing Construction Co.)
- 6) Tracoba (Industrialized Building Systems)
- 7) Wates (Wates Limited)

Early in most interviews the discussion would turn to the Ronan Point disaster. The failure itself, public and government reaction, interim revision of standards, and proposed new regulations were described. Professional comment on proposed amendments to the Building Regulations stemming from the disaster had been requested by the Ministry of Housing and Local Government on May 30, 1969, to be received no later than July 11, 1969. It was thought that a proposal based on these comments might be enacted as law early in 1970. On this basis the new regulations were adopted, thus delaying acceptance of the Bison, Tracoba and Camus systems.

One of those interviewed, Dr. William W. Chan, Chief Structural Engineer of the National Building Agency (NBA), emphasized the need for continuity of steel reinforcement in floors and in vertical load-bearing walls. He noted that an analysis of existing large panel structures in Britain had been completed. Some 50 to 60 apartment blocks averaging 80 dwellings each, or some 4,400 dwelling units, needed to be strengthened. Typical corrective work included steel angles dowelled to concrete panels at floor to wall joints, and auxiliary concrete or tubular steel columns installed at flank walls, but independent of the wall panels.

HUD OPERATION BREAKTHROUGH

A program to encourage industrialized housing concepts was announced on May 8, 1969 by George Romney, then Secretary of the U.S. Department of Housing and Urban Development. "Operation Breakthrough" was to be a total development program to resolve a multitude of problems associated with making quality housing available in large quantities. Its aim was to utilize modern design technology and contemporary approaches to financing, marketing, land use and management. One major objective of the program was to demonstrate that with the kind of large, continuous market enjoyed by manufacturers of other consumer products, producers of housing in volume could realize economies of scale. With such a market they could recover their investment in research and development, design, and plant and equipment necessary for volume production (9).

Five thousand Requests for Proposals (RFP's) were extended to local governments, private citizens and organizations, site planners, site developers and housing systems producers. Two kinds of proposals were sought: Type A for design, testing and evaluation of complete housing systems ready for production (255 received); and Type B for research and development of advanced concepts, materials and components, in process of development but not yet ready for production (388 received). Over 1000 firms were involved in the preparation of the proposals; many were the nation's most experienced housing professionals and producers and many had fresh new approaches to the housing problem.

industrialized construction for HUD 17

The volume of replies was far greater than expected, and the job of evaluation and selection was a monumental task for HUD's Office of Research and Technology (Now Office of Policy Development and Research). A 14-member Proposal Evaluation Board was set up, assisted by over 80 committee members drawn from HUD and other government agencies (9).

Initial evaluation reduced the total number of Type A proposals to 136 determined to be responsive. The Board then took a rank order vote and selected 37 systems for further consideration. These proposers were interviewed by the Board for an assessment of marketability and cost realism. On February 26, 1970, Secretary George Romney announced 22 housing system finalists. Of these, seven were industrialized concrete systems or systems using large industrialized concrete components in combination with other materials (9):

1. Building Systems International (Balency System) (panels)
2. Descon/Concordia Systems, Ltd. (panels)
3. FCE-Dillon (panels with utility modules)
4. Townland Corp. (precast frames and floors)
5. CAMCI Inc. (Tracoba No. 1 System) (panels)
6. Rouse-Wates Co. (Wates System) (panels)
7. Shelley Systems, Inc. (modules)

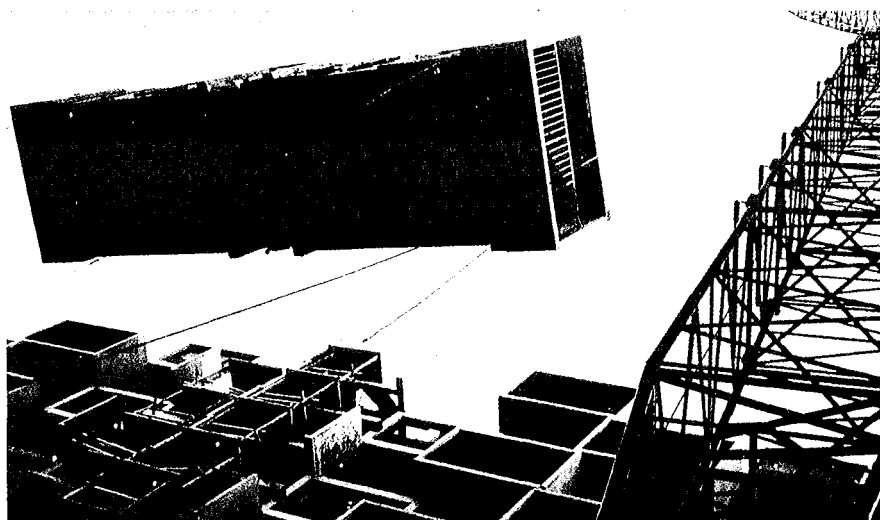
In order to adequately demonstrate housing systems while enabling evaluation of their technical and user-oriented aspects, prototype demonstration sites, free from constraints of codes and other factors, were required. Prototype sites were selected by national competition, with communities proposing specific parcels of land and assuring cooperation in the demonstration of housing and planning innovations. Each Prototype Site Community also agreed to waive any constraints in its building and zoning codes to permit use of innovative systems. Eleven sites were selected from over 200 proposed (two were later dropped because of budgetary considerations).

Eight Prototype Site Developers were selected to manage site construction, administer construction contracts with various producers during the demonstration and marketing period, and market the housing upon completion.

Prototype Site Planners were selected by competition from a list of 82 proposals. These were teams, made up of architects, landscape architects, site planners and engineers; engaged to develop and execute innovative land use designs. They were to collect and analyze site data, prepare conceptual designs for HUD review and approval, coordinate the various housing systems assigned to each site, and develop specific design and construction documents for site development (12).

Early in the planning for Operation Breakthrough, HUD determined that it was necessary to develop performance criteria to truly evaluate innovative and technologically advanced housing systems. HUD therefore consulted with the National Academies of Science and Engineering, and commissioned the National Bureau of Standards (NBS) to develop such criteria. A comprehensive Guide Criteria was developed and published as an Interim Draft in December 1970 (9).

18 industrialized concrete construction



Shelley System, Jersey City, N. J. HUD Operation Breakthrough, 18 story highrise, typical module, full building width



Shelley System, Jersey City, N. J., HUD Operation Breakthrough, 18 story highrise under construction

industrialized construction for HUD 19

The subject of "progressive collapse" was of utmost concern to HUD in evaluating concrete panelized systems, and became important in the development of the Guide Criteria. Section A.2.4 of the Criteria, titled "Catastrophic Loading," presented, in performance language, brief requirements for designing to avoid progressive collapse. This was, as was FHA's earlier "Minimum Tie Requirements to Prevent Progressive Collapse," (described later under "HUD Progressive Collapse Criteria") based on the British recommendations.

As the conceptual designs of the proposed housing systems began to take form, an NBS technical review was initiated. An evaluation team from the NBS, Center for Building Technology was established to ascertain, through review of drawing and specifications, compliance of each housing system design with the Guide Criteria. Because of the innovative features of some designs or the use of new materials, NBS required supplemental physical testing, primarily to ascertain compliance with structural and fire performance requirements.

Operation Breakthrough was originally conceived as a prototype program to be tested by actual occupancy and certified after a period of satisfactory performance. Design was considered as Phase I and construction, Phase II. Certification was then necessary to use the systems under Phase III, volume production under private enterprise leadership (9).

Many systems proposed for Operation Breakthrough had been accepted or were being reviewed by the Federal Housing Administration. It became expedient as an alternative to certification, to require the issuance of an FHA Structural Engineering Bulletin for each system proposed for Phase III construction. The seven industrialized concrete systems previously listed therefore submitted documentation to FHA and the NBS evaluation and test results were made available for FHA's review.

The Tracoba No. 1 system was submitted to FHA prior to Operation Breakthrough, and was issued SEB No. 695 on December 4, 1970. Under Breakthrough 150 multifamily highrise units were constructed on the Jersey City site. Similar units are proposed for construction under the FHA 236 program.

A joint venture between Wates Limited of London and Rouse Company in the U.S. was formed in May 1970. Rouse-Wates in turn engaged Ove Arup Partnership of London to act as structural consultant. Their submission for acceptance by FHA resulted in SEB No. 722, issued July 27, 1971 for construction up to 20 stories. Under Phase II of Operation Breakthrough they constructed 84 highrise, 27 medium-rise and 130 low-rise units on the St. Louis site. For Phase III, Rouse-Wates developed joint ventures with the George Hyman Co. for construction in the Maryland area, and with Carabetta Enterprises in Connecticut. In the St. Louis area Rouse-Wates is the general contractor for several proposed projects.

In October of 1971, the factory-cast modular Shelley System developed in Puerto Rico was submitted to FHA. NBS made structural tests to

20 industrialized concrete construction



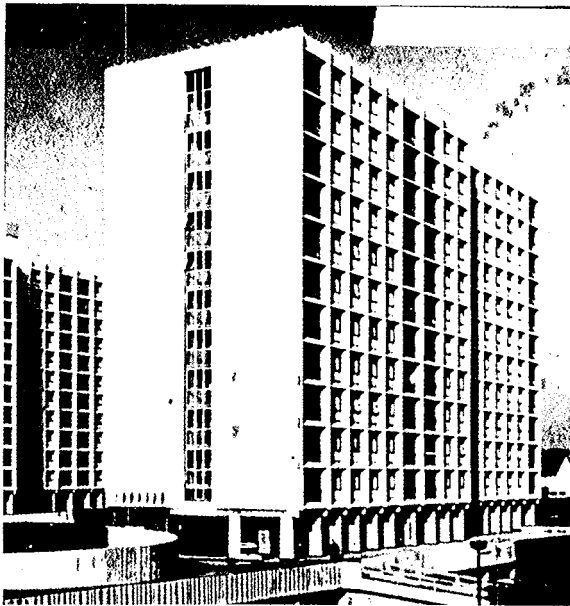
F.C.E.--Dillon System, Sacramento, Calif., Highrise and lowrise buildings for HUD Operation Breakthrough



F.C.E.--Dillon System, Sacramento, Calif., HUD Operation Breakthrough, 9 story highrise



Rouse-Wates System, St. Louis, Mo., Medium rise building for HUD Operation Breakthrough



Rouse-Wates System, artists rendering of 12 story, HUD Operation Breakthrough project, St. Louis, Mo.

22 industrialized concrete construction

analyze the complicated box modules and integral frames. SEB No. 773, issued March 29, 1972, covered 20-story construction in Seismic Zone 3. Phase II projects at the Jersey City site included 152 highrise units and 40 medium-rise units of this type. Phase III construction is planned in New York and Puerto Rico.

One of the most successful systems developed for Operation Breakthrough has been the Dillon System. This variation from the typical European panelized system was submitted to FHA by FCE-Dillon, Inc. (Shelter Systems, Inc.) in November 1971. SEB No. 784 was issued May 18, 1972. Of the industrialized concrete systems, it has been used on more Breakthrough sites than any other system. The Dillon System replaced Stirling-Homex on the Memphis site for a 213 unit multifamily highrise building and on the Kalamazoo site for 54 units of multifamily medium-rise construction. The Sacramento site (112 units, highrise) and Indianapolis site (60 units, five story medium-rise) were Dillon's other Phase II locations. Over 840 dwelling units have been completed under Phase III and another 2300 highrise and medium-rise units are under construction either as Phase III projects or FHA programs.

The last "Breakthrough" concrete system accepted by FHA was submitted by Descon/Concordia Systems, Ltd. of Canada, in March 1972. The Descon/Concordia Precast Building System consists of panelized concrete walls and floors with bolted connections. SEB No. 820 was issued on December 8, 1972 to cover buildings up to 14 stories high. Phase II construction consisted of 90 highrise, 24-medium-rise and 14 lowrise units at the St. Louis site and 111 highrise, 18-medium-rise and 12 lowrise units on the Jersey City site. To handle Phase III projects, two licensees were organized: Descon/Concordia Systems of New England and Descon/Concordia Corporation of California.

Only two of the Breakthrough concrete systems have not as yet received SEB's: Building Systems International (Balency) and Townland Marketing and Development Corporation. The Balency request was submitted to FHA in September 1968, and the Townland request was submitted in August 1972. These Breakthrough prototypes were reviewed, but proposed production under Phase III has been delayed due to financial, organizational or processing problems. It is anticipated that both systems will be accepted for construction by HUD in the near future.

HUD PROGRESSIVE COLLAPSE CRITERIA

Between the time of the September 1969 HUD staff trip to England and France and the latter part of 1970, technical data concerning the need for vertical and horizontal ties was relayed by HUD to the proponents of the Coignet, Cebus, Bison, Camus, Tracoba and Balency systems. A section titled Ties, Tie Beams, Vertical Ties, and Provision for the Prevention of Progressive Collapse was contained in SEB No. 544 (dated August 28, 1969) which was issued to Concrete Ltd. (Bison) in April 1970. Similar sections were prepared in draft form to supplement bulletins issued to Coignet and Cebus. The bulletin issued for the Bison System, pending bulletins for Tracoba and Camus and the revisions to those for Coignet and Cebus were all delayed by the HUD trip to Europe and anticipation of British regulations.

industrialized construction for HUD 23

The development of a comprehensive document to adequately design to resist progressive collapse was started in early 1970, when HUD sent letters to key organizations: The American Concrete Institute (ACI), Portland Cement Association (PCA), Prestressed Concrete Institute (PCI), American Society of Civil Engineers (ASCE) and National Bureau of Standards (NBS). HUD outlined the problem as perceived: the ACI 318-63 building code was oriented toward framed structures, therefore numerous factors peculiar to large precast concrete panel construction were not covered. HUD suggested that a code be developed for this type of construction: one section to apply to normal gravity and lateral loadings, and another section containing provisions for accidental and unusual loadings with limitations placed on extent of permissible damage.

At the ACI Annual Convention in April 1970, HUD discussed with ACI personnel the fact that neither Committee 533 "Precast Panels" nor Committee 322 "Residential Concrete" assumed the responsibility for precast concrete shear wall panels in highrise buildings. HUD then suggested, by letter dated May 6, 1970 to ACI, that a committee be established to address the specific problem, or that the problem be given priority by an existing committee. Information recommended for study was mainly that being derived by the United Kingdom and used as a basis for HUD's criteria.

In April 1970 the British Parliament approved the "Fifth Amendment" to the 1970 Building Regulations which made it mandatory for all buildings of five or more stories to be designed to resist progressive collapse (11). This document contained the two methods of analysis previously recommended in the 1968 "Standards to Avoid Progressive Collapse - Large Panel Construction." Structures submitted to HUD were required to be analyzed by the "Alternate Path Method" or designed to withstand the equivalent of 5 psi static pressure as prescribed by the Fifth Amendment.

A bulletin supplement was issued to Coignet in September 1970 which contained a section "Ties, Tie Beams, Vertical Ties, and Provisions for the Prevention of Progressive Collapse" with pertinent connection details. Laced loop bars were provided in horizontal floor/wall joints and vertical castellated wall/wall joints. Continuous vertical hangers were prescribed for all bearing wall panels.

Relbec Corporation of Rio Piedras, Puerto Rico submitted a design based on the revised Larsen-Nielsen System in April 1970 and was issued SEB No. 673, dated September 4, 1970. Laced loop bars were provided in horizontal and vertical joints and continuous vertical reinforcement was placed in bearing wall panels with special connectors used at each floor level.

The Tracoba No. 1 System was then accepted by way of SEB No. 695, dated December 4, 1970 which contained provisions similar to the Coignet bulletin but titled "Prevention of Progressive Collapse". Special steel connectors were detailed for continuous vertical ties in bearing wall panels and laced loop bars were provided in horizontal and vertical joints.

24 industrialized concrete construction

While HUD continued processing acceptances of precast concrete panel systems based on limited knowledge of abnormal loadings and progressive collapse, the British Code Drafting Committee BLC/35-Precast Concrete continued to develop criteria as specifically recommended by the Ronan Point Inquiry Report. Their effort was reflected in publication in November 1970 of Addendum No. 1 (1970), "Large-Panel Structures and Structural Connections in Precast Concrete" to the British Standard Code of Practice CP116, "The Structural Use of Precast Concrete." In effect the committee adopted the criteria contained in the former 1970 Building (Fifth Amendment) Regulations. Structural Engineering Bulletins and revisions of supplements to SEB's were issued to systems that complied with the "Alternate Path" method of analysis as specified in Addendum No. 1 to CP116. Camus was issued SEB No. 719 (July 15, 1971) which, upon their recommendation, contained a complete section on "Prevention of Progressive Collapse" which described the alternate path method as well as the pressure design method. Other bulletins and revisions, however, containing only a brief requirement for continuous vertical hangers and horizontal ties, were issued to Rouse-Wates (SEB No. 722, 7/27/71), Jespersen-Kay Systems, Ltd. of Canada (SEB No. 748, 10/14/71) and Cebus (SEB No. 455, Revised 7/13/71).

There still remained the problem of inadequate code provisions for precast buildings. Little action by professional organizations was observed, so in February 1971 HUD again wrote to ACI, PCA, PCI, ASCE and NBS. Copies of Structural Engineering Bulletins which considered "Progressive Collapse" and also copies of the British Code of Practice CP116 were enclosed. HUD solicited comments and recommended development of criteria. This letter prompted the American Concrete Institute in April 1971 to form a new committee on "Industrialized Concrete Construction," ACI Committee 356. Its charge was to first study HUD's document and then to consider code provisions specifically for precast panel buildings. At the suggestion of ACI, HUD appointed a member and an alternate member to the Committee.

A few months later, the Prestressed Concrete Institute established a similar committee titled "Large Precast Concrete Panel Construction" to review the HUD criteria and to develop a recommended practice for the design, manufacture and erection of precast concrete bearing wall buildings. HUD is also represented on this committee. Both the ACI and PCI committees began an intensive effort to evaluate the HUD criteria and develop adequate standards, which hopefully would preclude the necessity for separate criteria by the Federal Housing Administration.

HUD developed and sent to industry, in October 1971, copies of revised criteria based on the British CP116. This document was titled "Provisions to Prevent Progressive Collapse - Proposed Revisions to Structural Engineering Bulletins for Highrise Precast Concrete Buildings." There was immediate reaction against the criteria, mainly by members of the precast concrete industry. They felt that their type of construction was being singled out to meet excessively stringent requirements. Even though the HUD criteria began as a document intended for manufactured housing systems covered by SEB's, HUD could not imply discrimination against one sector of the building industry. Several

members of ACI Committee 356 expressed their criticism of the limited applicability of the document at the ACI Convention in Buffalo in November 1971 and correspondence registering similar objections began to flow to HUD from other representatives of the precast industry.

It was obvious that the criteria must cover all types of building construction. Particular reference, however, could be made to systems which, if not designed and constructed properly, would be susceptible to progressive or incremental failures when subjected to an abnormal loading.

HUD therefore prepared a draft circular in April 1971, "Prevention of Progressive Collapse in Tall Buildings," with intended issuance to all HUD offices to apprise them of the potential hazard. The circular was intended to transmit "Interim Criteria for Prevention of Progressive Collapse." Contained in these criteria were minimum tie requirements and methods of analysis without reference to any particular type of building. Several revisions, recommended by industry, were incorporated to remove ambiguity and to clarify portions of the preceding document.

Specific minimum tie requirements for masonry buildings were then provided in an August 1972 revision of a proposed circular, "Structural Design of Buildings to Avoid Progressive Collapse." Its stated purpose was: 1) to notify HUD offices of the potential hazard of progressive collapse and 2) to provide criteria for the structural design, review and construction of buildings under HUD programs.

To more thoroughly review this new draft document, HUD called together the local representatives of ACI, NBS and the masonry industry on September 7, 1972. Again several minor changes were made to the criteria, but its format and content remained virtually intact.

A vote of confidence for the HUD criteria was expressed October 20, 1972 at the PCI Annual Convention in Atlanta. During a building design seminar, Alexander Popoff, Jr. of ABAM Engineers, Inc. presented a paper "Designing Against Progressive Collapse." His philosophy was as follows: "Many generations of engineers have given me the answer: tie the building together, provide some ductility, do not blindly follow the code, be conservative when there is doubt." He proceeded to describe the design of a multistory precast component building. Reinforcement and ties were designed and compared with those resulting from the requirements of HUD. It was shown that each requirement of HUD's "Minimum Connections, Ties and Reinforcement" was exceeded. The design also complied with numerous foreign practices relating to progressive collapse. He concluded that design codes do provide necessary safeguards if engineers use good judgment and do not ignore continuity, but that a detailed recommended practice manual is needed for precast concrete construction, particularly for highrise buildings. The questions Mr. Popoff did not answer are: Do the majority of engineers use good judgment, do they have the inherent intuition (usually developed - like wisdom - with time) to design a building to act as a unit and not as individual components, or do many use codes as strictly minimums without a proper evaluation of resistance to forces?

26 industrialized concrete construction

The need to design for abnormal loads has been seriously questioned by many structural engineers and architects. A statistical study of the incidence of abnormal loading was therefore considered to be an important factor when assessing the possibility of progressive collapse. The National Bureau of Standards conducted such a study which was reported at the "Building Practices for Disaster Mitigation" workshop in Boulder, Colorado in the fall of 1972 (13). A report by Dr. Norman F. Somes of NBS supported HUD's position that abnormal loads were a potential hazard, and that failure to consider such loads could lead to insufficient design of some systems. Dr. Somes pointed out that by adding the number of incidents of gas explosions, vehicular impact and sabotage bombings, the probability of occurrence of abnormal loads in the U.S. would be higher than that of "town gas" explosions in Great Britain. It is a problem that cannot be ignored! Why "close the door after the horse is stolen" when loss of life and property can be prevented with little, if any, increase in cost of the structure?

Structural Design Philosophy

The following performance statement has been the basis for the HUD-FHA Criteria dealing with resistance to progressive collapse and should be kept in mind by all designers of structures intended for human use or habitation:

"Joints between prefabricated structural elements used as columns, beams, bearing walls, or slabs should develop continuity similar to that provided by conventional cast-in-place concrete or structural steel framing systems. In regions not subject to severe seismic or wind action, connections should not be designed solely as gravity-type relying only on compression and friction. Where severe seismic forces are highly probable (Seismic Zones 2 and 3), connections, in particular should be examined. Their response to dynamic forces must be evaluated, e.g., vertical castellated and grouted joints may be completely satisfactory for quasi-static earthquake design loads but could shake apart under actual dynamic, oscillatory earthquake forces.

Joints between floor elements should develop adequate diaphragm action in order that the entire floor system may transmit lateral forces to the vertical elements. Peripheral ties completely encircling the building are also considered necessary to develop this diaphragm action. Vertical and horizontal joints between vertical structural elements must develop necessary continuity and deformability to transmit the lateral forces to the foundations."

The intention of this philosophy is that if any individual structural element is damaged or destroyed by an abnormal loading, the remaining structure must retain its stability and shall not fail. Damage must also be limited (as recommended by HUD) to 1000 s.f. or 20% of horizontal floor area (whichever is less) on any one floor, and to three stories vertically. Elements and connections must distribute forces via an alternate path around the damaged portion or they must be designed for a force of 5 psi (720 psf) to resist removal of the element. The 5 psi figure was developed from the Ronan Point inquiry and seems to be an average pressure for that type of gas explosion.

Various types of explosions yield lower values, especially if venting is experienced, but since solid explosives yield higher unidirectional peak pressures in a much smaller time frame, research must be conducted to substantiate revising this design pressure.

Our present criteria are now in the form of a HUD Handbook proposed for publication in mid-1974. The latest draft, dated November 1973, titled "Structural Design Requirements to Increase Resistance of Buildings to Progressive Collapse," is almost identical to the former draft circular. During November this draft criteria was mailed to all 88 Regional, Area and Insuring Offices of HUD and to over thirty representatives of industry for further review. Comments and criticism are still being received. We intend to classify all of the comments in similar categories to simplify replies to each correspondent.

Now that we have tackled one of the major problems affecting residential units constructed under HUD programs, what is the next step? What is to be done about building systems privately financed and constructed which are not covered by HUD Minimum Property Standards, Structural Engineering Bulletins, or other HUD criteria? Will the occupants of those buildings be equally protected? These questions remain to be answered.

CONCLUSIONS

Industrialized Concrete Production for HUD

Tabulated herein are the concrete systems that have been constructed under the many HUD/FHA programs. At present this information is incomplete as some data was unavailable. There also may be several industrialized concrete buildings constructed in local areas which have been processed solely by a HUD field office. Established HUD procedures enable HUD offices to retain a certain amount of autonomy when processing and accepting construction in their jurisdictional areas. They may have the technical expertise at hand or they may accept the certification of reliable professionals when processing individual projects.

Systems Development

With few exceptions, prefabrication of large building components has been unable to thrive without some form of assistance, guarantee or underwriting by a public body. Guaranteed scale and continuity of production are necessary for success.

This was clearly demonstrated in Europe. East European countries generally exhibited a greater use of industrialization for residential construction than did West European countries. The mixed success of industrialized systems in West Europe must take into account their lack of cost-reduction potential. Substantial external economies can probably only be achieved under a long-term comprehensive industrialization program subsidized by the government (6).

28 industrialized concrete construction

HUD's "Operation Breakthrough" initiated an effort in this direction that generated considerable interest. Many manufacturers, accepted under that program, have successfully continued vigorous, on-going production schedules. HUD experience has shown that concrete box-module systems seem to have the most difficulty in sustaining long-term success. Even though the research project in 1968 by IITRI (7) predicted that box-like modular systems were the ultimate solution to the housing shortage problem, very few have achieved success. A primary difficulty seems to be that complexity of forming, with the integration of utilities, inserts, and connections, escalates costs.

Another adverse factor encountered with modular systems, and to a lesser degree with panelized systems, is the tremendously high investment required for manufacturing and transportation facilities. Unless a company can be guaranteed a minimum number of components per year, it cannot afford to construct an expensive factory containing thousands of dollars worth of equipment and to invest in costly, specialized transportation equipment.

Aesthetics seems to be another drawback. Architectural flexibility is not as easily obtained as with conventional construction methods. Modular systems have been very successful in the Soviet countries, for example, but mainly because quantity has priority over quality.

The most successful concrete systems thus far in the U.S. seem to be panelized construction incorporating utility modules. These systems have much more architectural flexibility, maintain speed of erection, and can incorporate quality control measures in the factory. Functional layouts must be flexible in order to utilize any one of several utility cores available on the market. Transportation distances must be kept to a minimum, however, preferably requiring a maximum travel of one-day round trips.

Industrialized concrete construction is still in the embryonic stage. If past experiences are heeded, this type of construction should account for a large percentage of the residential market.

Design Standards

The Ronan Point Apartment collapse in 1968 presented a hurdle to the precast concrete industry both here and abroad. However, the industry through research and involvement of organizations such as ACI and PCI has rallied to provide concrete systems that will be as safe if not safer than other construction methods. Development of standards in 1974 will certainly assist designers in providing for abnormal loadings by requiring that continuity be provided between all load-carrying elements of a building.

HUD's proposed criteria for design to resist progressive collapse was a catalyst to the development of adequate design standards for precast concrete bearing wall buildings. It has come under considerable attack by many representatives of the design profession but establishment of adequate code provisions by the concrete industry has been fostered.

The masonry industry has also begun to investigate the problem of inadequate continuity in masonry bearing wall buildings. Hopefully, recommendations will be adopted by major code-writing bodies which will preclude adoption of a separate HUD document.

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Table No. 1 Precast Concrete Systems Constructed Under HUD Programs

SYSTEM PROPONENT	SYSTEM TYPE	SEB NO. TYPE	HUD/FHA PROGRAM	NO. of DWELLING UNITS	NO. of STORIES	TOTAL COST (millions)
1. Building Systems International (Balency System) Atlanta, Georgia	Panels	- - - -	Operation Breakthrough Phase II	56 HR 24 MR	12 6	- - - - - - - -
2. Camus (Gt. Britain) Ltd. (Camus System) Surrey, England	Panels	719 7/15/71	(No construction in U.S. at present)		- - - -	- - - -
3. Cebus USA, Inc. Tadjer & Cohen Assoc. Silver Spring, Maryland	Panels	455 Rev. 7/13/71	FHA 236	123 MR	7	\$1.8
4. Constructions Edmund Coignet (Coignet System) Paris, France	Panels	482 Supp.#2 9/17/70	(No construction in U.S. at present)		- - - -	- - - -
5. Concrete Limited (Bison System) Middlesex, England	Panels	544 8/28/69				
a. Blakeslee & Sons New Haven, Connecticut	"	"	Public Housing - Turnkey & FHA 207	503 HR 278 MR	10,17 4-6	\$8.8 \$4.3
b. Dickerson Co. Pittsburgh, Pennsylvania	"	"	Public Housing - Turnkey	100 HR 60 MR	9 6	\$2.0 \$1.0
c. Strescon Industries, Inc Baltimore, Maryland	"	"	Public Housing - Turnkey	100 MR	6	\$2.2
6. Descon/Concordia Systems, Ltd. (D/C System) Montreal, Canada	Panels (Bolted)	820 12/8/72	Operation Breakthrough Phase II	201 HR 42 MR 26 LR	11 6 3	- - - - - - - - - - - -
a. D/C New England and D/C California	"	"	FHA 236	629 HR	12-18	\$14.2

Industrialized construction for HUD 31

Table No. 1 (Cont.)

7. FCE - Dillon, Inc. (Dillon System) Akron, Ohio	Panels	784 Rev. 7/2/73	Operation Breakthrough	325 HR	9,13	- - - -
			Phase II	114 MR	4,5	- - - -
			Operation Breakthrough	1020 HR	9-15	\$14.2
			Phase III - FHA 236	510 MR	6,7	\$6.8
				72 LR	21/2-3	\$1.4
			Operation Breakthrough	562 HR	8-12	\$ 9.5
			Phase III - Other			
			FHA 236	382 HR	9,10	\$ 5.8
8. Sepp Firnkas Engineering (Firnkas System) Boston, Massachusetts	Panels	- - - -	FHA 221(d)3	264 HR	9,12	\$ 4.1
				580 MR	4,6	\$ 7.3
				332 LR	3	\$ 4.3
			FHA 231 - Housing for	896 HR	8-17	\$14.5
			Elderly	639 MR	4-7	\$12.1
				154 LR	2	\$ 1.8
			FHA 236 - Rental Housing	2748 HR	8-19	\$38.8
				544 MR	4,6	\$12.3
9. Industrialized Building Systems (Tracoba System) Darien, Connecticut	Panels	695 12/4/70	Operation Breakthrough	150 HR	16	- - - -
			Phase II - FHA 236	450 HR	15	\$16.8
10. Jespersion-Kay Systems, Ltd. (Jespersion System) Don Mills (Toronto), Canada	Panels	748 10/14/71	N.A.	N.A.	N.A.	N.A.
11. Relbec Corporation (Larsen-Nielson System) Hato Rey, Puerto Rico	Panels	673 Rev. 11/30/72	FHA 235	662 HR	10-14	\$10.4
12. F. D. Rich Housing Corp. (HAB System) Stamford, Connecticut	Modules	741 9/16/71	(Prototype construction only - new plant under construction)			



Table No. 1 (Cont.)

13. Rouse-Wates, Inc. (Wates System) Columbia, Maryland	Panels	722 7/27/71				
a. George Hyman Constr. Co.	"	"	Operation Breakthrough Phase III - FHA 236	517 HR	8-14	\$10.8
b. Carabetta Enterprises New Haven, Connecticut	"	"	FHA 221(d)4 FHA 236	620 HR	17	\$15.4
c. Rouse-Wates of St. Louis St. Louis, Missouri	"	"	Operation Breakthrough Phase II	84 HR 27 MR 130 LR 322 HR	N.A.	- - - - - - - - - - - - \$ 6.5
14. Shelley Systems, Inc. New York, New York San Juan, Puerto Rico	Modules	773 3/29/72	Operation Breakthrough Phase II FHA 236	152 HR 40 MR 1700 HR	18 6 15-18	- - - - - - - - \$55.0
15. Stressed Structures, Inc. (Uniment System)	Modules	677 9/23/70	FHA 233 Experimental Housing	24 MR	6	\$0.54
16. Townland Marketing & Devel. Corp. (SLS System) New York, New York	Frame*	- - -	Operation Breakthrough Phase II *Precast concrete frame supports steel and wood frame modules. Considered as Single-Family attached units.	38 MR 20 LR	4* 3*	- - - - - - - -
17. Wham, Inc. (WHAM-T Method) Memphis, Tennessee	Modules*	774 4/4/72	FHA 236 *Tee-shaped units form floor and wall units.	196 HR	13	\$ 3.2

- Notes: 1) Total Cost figures are rounded off and cannot be used for cost comparisons.
Operation Breakthrough, Phase II costs are not listed because prototype costs cannot be correlated.
- 2) HR - Highrise multifamily units, 8 stories and above
MR - Midrise multifamily units, 4 to 7 stories
LR - Lowrise multifamily units, 1 to 3 stories

SP 48-3

U.K. EXPERIENCE WITH INDUSTRIALIZED CONCRETE CONSTRUCTION

BY

F.W. Gifford

Synopsis: The paper reviews the development of the structural precast concrete industry in the U.K. over the last 15 - 20 years, specifically in terms of the activities of Concrete Limited, and generally as regards other companies, with particular regard to the development of an industrialised system of construction for various markets - apartments, car parks, offices, schools, etc., and flooring generally; it comments on current markets. It discusses the problems which have arisen as a result of Ronan Point and the subsequent activities including Building Regulations and existing Codes of Practice and the recently issued Unified Code based on Limit State Design. It briefly touches on differences between the U.K. and America.

Keywords: building codes; concrete construction; floors; high-rise buildings; industrialized buildings; masonry; precast concrete; prefabrication; project planning; standards; structural design.

36 Industrialized concrete construction

Dr. F.W. Gifford has specialised in structural precast and prestressed concrete since 1947; he joined Concrete Limited in 1956 and has subsequently been responsible for all the structural engineering and technical development. He has written and presented many papers and lectures, and served on a wide range of engineering committees and councils.

INTRODUCTION

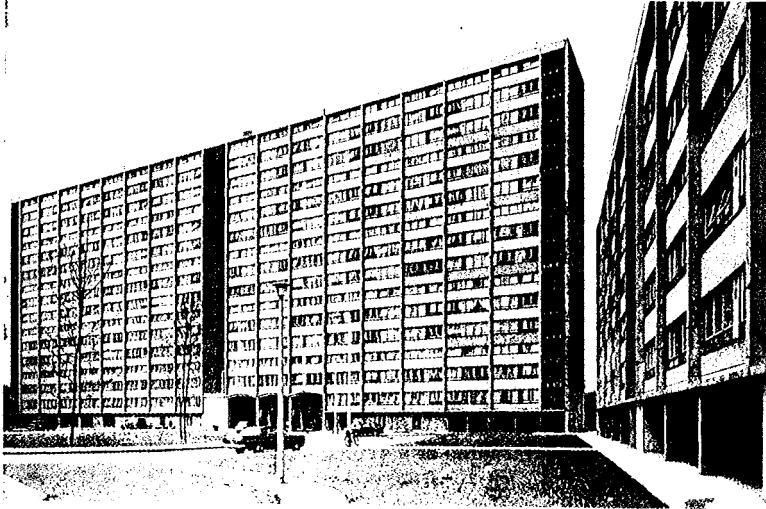
This Paper deals with industrialised production using structural precast concrete for buildings, comprising floors and supporting structural members, with or without concrete cladding; to the author this implies a 'system' approach using a range of components which can be produced from a basic set of moulds, there being a convenient modular change from one unit to another and it also means that instead of the original concept of the planning of a building being defined by an architectural layout and the structure subsequently fitted to this, the planning of the building is directly associated with the structure (including relevant cladding), by which means it is possible to derive the substantial advantages of a reasonable degree of standardisation.

It should be noted that all dimensions, etc, in this paper are in inches, feet, pounds, etc., which is intended to help readers. In the U.K. the metric system is now in use.

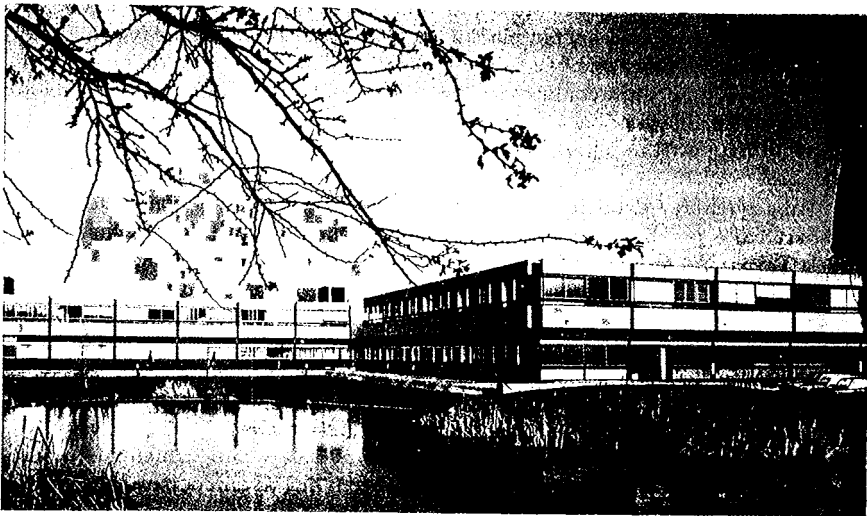
HISTORICAL DEVELOPMENT

1947, Concrete Limited was a small firm with a turnover of \$1m, manufacturing Bison reinforced concrete precast floor units with cavities formed by patented withdrawable inflatable stiffened cores. The advent of the concept of long line prestressing coupled with the then shortage of building materials resulted, in 1948, in the pretensioned hollow floor unit which has been the basis of the Company's development; in 1952 the pretensioned soffit plank for use with poured in place structural topping was introduced and in 1953 the wide slab (multi core) unit. The first (single storey) frame was introduced in 1954 (turnover \$8m) and 1956 saw the introduction of 4 and 9 storey precast structures, comprising multi storey lifts of columns, beams and wide slabs, with cast in place stiffening walls.

1958 (turnover \$16m) saw a 10 storey H frame College of Technology and a 16 storey apartment block 300' long (constructed totally of precast wall units and wide slab floor units). The apartment block had externally finished load bearing gable walls and fascia spandrels; internal wall units (many two storey) were cast flat; the whole interior had applied insulation and plaster. Shortly afterwards three 16 storey apartment blocks having



16 story apartment block 300 ft constructed in 1958 with seven similar 7 story blocks, basically using precast wall and wide slab floor units. One of the first major precast large panel housing developments in Europe



Warwick University, An excellent example of a completely standard early preferred dimension frame

38 Industrialized concrete construction

precast beams and columns were being constructed simultaneously with 3 other blocks built by another constructor, and designed poured in place, but otherwise identical. The difference in construction time became extremely apparent to the client. 1961 saw the first Bison multi storey clear span car park, for 760 cars.

Development to this date had been very much "one off" and the need for systemisation was apparent; the first frame system (known as the Bison Preferred Dimension Frame) was introduced late in 1961; being based on a 2'6" wide floor unit which spanned across the building, the facade columns spacing was 10' - 20' in 2'6" increments; storey heights were 10', 11' and 12' and standard columns were cast in one piece up to 4 storeys. The essence of the system was that it was based on a limited number of steel moulds which could be adjusted modularly to provide a very large number of components which would meet a wide range of structures - provided the architect was prepared to accept the limited number of requirements of the modular concept. From the start the system was a success and the basic principles are still used, and the system has been copied in considerable detail by others.

The second frame system was for Multi Storey Car Parks; the second and third park built differed from the first, but the experience of these and the enquiries they generated led in 1962, to the Mark I Car Park system which was virtually the construction used in the very first park, with various details tidied up. Basically, the system was to use standard pretensioned inverted T Bridge Beams made composite with a 4½" floor constructed of 2½" thick pretensioned soffit planks and 2" structural topping. Using 9'4" storey height, 7' clear under beams, the 2'4" depth of construction meant that two bridge beams could carry 16' width of floor - and as the 4½" floor would span 16' it was found convenient to put pairs of beams at 16' centre onto 5'3" long walls - thereby eliminating primary beams spanning 16'.

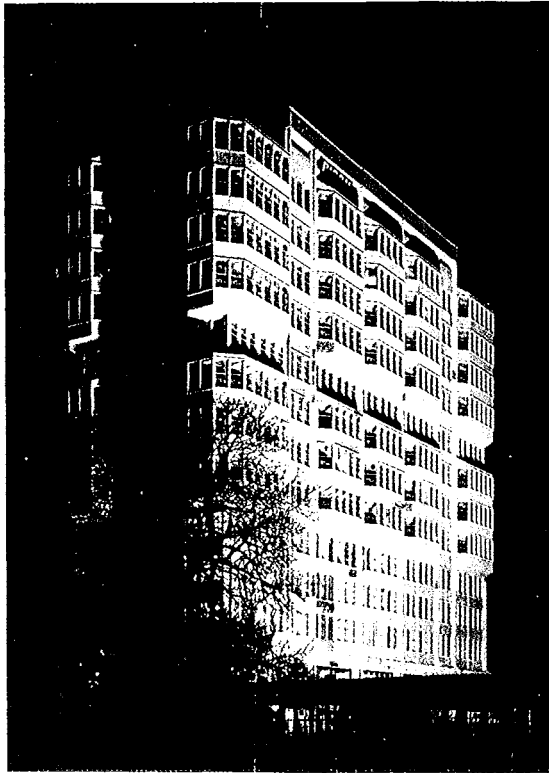
Subsequently, experience shows that the 2'4" depth of construction was not critical - neither because of the ramp slope for split level construction (i.e. alternative floors staggered half storey height) nor for overall height of building, and in consequence a more economical Mark II design was introduced in which the depth of construction was increased to 3', and using a single slightly deeper beam (again at 16' centres) sitting on an external column 24" x 11"; the latter was cast as a standard 2 storey lift, spliced about 4' above floor level. Ramp walls at split levels were reduced from 22' in length to 10', thereby reducing costs and improving traffic visibility, and the ramp wall unit was designed as a "universal" one, which enabled it to be used in any condition. Thus, apart from any architectural embellishments, the system is based on a few standard moulds - main pretensioned beams, 2 storey external columns, standard universal ramp walls, and standard internal walls. The Mark II system was introduced in 1966 and still going strong - it could be improved but the modifications affect main pretensioned beams and will await mould replacement.

On the (public) housing side, experience showed that major advantages would result from rationalising the construction - that is, having a definite product or system. Load bearing walls had become well established, the elimination of plaster by vertical casting or horizontal casting and floating off smooth was practical, and hung on cladding had been made structural eliminating the frame; furthermore there was evident need for something positive to offer, which had been well thought out, and yet providing a wide freedom of expression. This led to the development of the Bison Wall Frame System for High Flats in 1962 (turnover \$24m), and the occupation of the first of those flats in 1963. In about a year 19 local Council Authorities had placed 25 contracts for over 50 blocks comprising nearly 3,500 dwellings and within two years one fifth of all high rise blocks were built in the system. Wall Frame developed to be by far the most successful concrete panel system in the U.K.; fundamentally it was aimed at the public housing market of 8-24 storeys and within the very broad possibilities of the system it provides, in the U.K., without doubt the most economical form of construction of high blocks of flats; it has been used from 4 storeys upwards.

Late in 1964 (turnover \$36m) a further housing development was introduced - the Bison Low Rise System; this was aimed at the market up to 8 storeys and was essentially a cross wall construction, but with substantial provisions for "deck access" - at the time in the U.K. an architectural fashion had developed of having decks at (typically) every third floor, which deck would provide access not only for pedestrians, but small delivery vehicles - e.g. milk, etc., is delivered daily in most cities in the U.K. Many substantial developments were carried out with the Low Rise System used on deck access jobs but these were much less rewarding financially - this type of architectural planning means that the apartments are unnecessarily expensive, and since construction was to be very tight budgets, margins were minimal; the planning also produced environmental difficulties (mainly acoustic and thermal) and costs of solving these inevitably partly came back to the structural precast concrete contractor; the layout of the blocks resulted in far less repetition and far more difficult problems on site than with the relatively straightforward high rise.

In 1967 the Bison PD2 Frame was introduced as a development of the earlier Preferred Dimension Frame; during the intervening years, modular construction had gained ground and the Government issued directives on its use for schools, hospitals, offices, etc., PD2 was originally fully modular and fully prestressed - i.e. in addition to floor units, column and beams (both internal and external). Floor slabs were of constant thickness. Whilst the system was extremely well engineered within the criteria laid down it became apparent after a while that the criteria were not sound - the Government directives were generally ignored by its departments and local authorities as well as private firms; the volume of work did not justify the pretensioning of columns and external beams, the standard floor thickness was expensive (by our costing methods) on many spans, and the maintenance of a structure within the depth of floor zones was also costly and frequently

40 industrialized concrete construction



Bucks County Offices, Aylesbury, Tower Block. A one-off beam and column design built in 1965

unnecessary. Within about a year the PD2 System reverted from a fully modular system to one which could be fully modular if required, but gave much more options; it accepted non modular construction when it was suitable and economic; broadly the system reverted to one based on standard modular moulds and details, and this is used to this day, with the added facility of load bearing facade of sandwich or non-sandwich construction. The present system can cope with the bulk of normal buildings of the office block, school, university, factory type up to, say, 10 storeys and in the circumstances above; in practice the construction for offices using load bearing facades is currently most successful - where such a facade is acceptable; in this context a structural concrete facade includes any special facing material such as mosaics, marbles, bricks, etc.

The most recent development, within the last two years, in the introduction of Industrial Cladding - pretensioned cored units manufactured using long line techniques, 10' wide and up to 30' high, with a suitable (usually exposed aggregate) outer face (cast face up) and an internal face which for industrial purposes, can be decorated direct; the core which is a cheap plastic foam is an insulant. It appears that the sale of these units is expanding rapidly, one advantage being the difficulty of getting bricklayers and their high cost.

The Company originated as a specialist in precast concrete flooring and has always considered that the flooring product is its "bread and butter". It has obtained and retained the major share (at times over a half) of the specialist flooring market and has done this on the basis of a standard product which is adequately flexible for the needs of as many clients as possible. In this respect, whilst it has experimented over the years with casting machines, (and still is) and has considered all those available, at the present flooring is not machine made. The recent introduction of the patented foam core, metrication, and general economic pressures have led to a rationalisation of flooring with a view eventually to machine production.

The following summarises the standard pretensioned flooring production currently produced :-

- (a) Single voided fully precast units 16" wide from 4" to 16" deep in 2" increments for use on any form of supports; normally require finishes top and bottom.
 - (i) Square solid ends for any appropriate support.
 - (ii) Notched ends for sitting onto shelf angles of steel, or on casing; also used where the floor is required to act as the flange of a concrete beam.

42 industrialized concrete construction

- (b) Solid soffit planks 16" wide, 2", 2½", 3" and 4" thick, (to receive structural poured in place topping), soffit normally requiring finishes. Generally as (a) but used where the poured in place concrete is a specific advantage. Standard projecting end stirrups can be included, transverse or longitudinal, depending on function.
- (c) Multiple voided fully precast units 4' wide from 4" to 12" (3 voids), in 2" increments, and 14" and 16" (2 voids), for use on any form of supports, normally requiring finishes on top; soffit suitable for decoration direct if specified.
 - (i) Square ends (with castellations in end).
 - (ii) Nibbed ends
 - either with or without projecting steel - which if present is in the form of vertical loops on a 12" module, on plan.
- (d) Solid soffit planks 4' wide, as (b) but soffit suitable for decoration direct if specified:
- (e) Multiple voided fully precast units 6' and 9' wide manufactured virtually flat suitable for finishes direct top and bottom; these units are essentially the floor units of the Wall Frame System but can be used on other suitable construction.

With reinforced concrete units, these are now restricted, as standard, to single voided fully precast units 16" wide, 4", 6" and 8" thick. Nevertheless the inherent differences between the manufacture of reinforced as apart from pretensioned concrete floor units is the much less need for standardisation - and thus, where appropriate, wider, multiple core units can be easily made - it is of interest to note that in 1960 19,200 sq. yds. of Bison reinforced concrete wide slabs were built into the Queen Elizabeth II Grandstand at Royal Ascot - the slabs were such that only spray painting was necessary, and the whole Grandstand construction took under ten months.

A particular point which has always intrigued the author, and on which he would welcome comments, is the complete absence of double tees from Concrete Limited's products as sold - and the virtual absence of double tees as competition - various firms have, and some still do, make these units but they in no way are serious competition; we offer the unit but even on very large contracts it has never met the grade; apart from cost, the lack of flexibility once a mould is put down, the depth of construction and the problem of partitions - unless there is a false ceiling - are factors which weigh against it.

As a rough guide to Concrete Limited's activities now and during the last ten years the following table may be of use.

	1973		1968		1963	
	\$m	%	\$m	%	\$m	%
Flooring	25.2	36	18.4	30	7.2	30
Housing	10.4	15	37.2	60	12.0	50
Frames	25.6	37)				
Car Parks	5.6	8)	6.4	10	4.8	20
Other	3.2	4)				
TOTAL:	70.0	100	62.0	100	24.0	100

Note: Conversion from £ to \$ has been based on a realistic, not simple exchange rate.

In ten years the total number of dwellings built has been 31,000 in High Rise Wall Frame and 23,000 in Low Rise Wall Frame.

At least 36 private parks (usually associated with housing schemes), and 26 public parks (providing space for 19,000 cars) have been built since the construction of Multi Storey Car Parks commenced, most being to Mark I or II design modified as necessary.

Other British Companies have operated on a similar basis in varying fields, and on much smaller scales. An interesting point to appreciate is that no independent British precast concrete Company has survived without having a "standard" product to sell - invariably those who only manufactured "specials" to others' designs sooner or later have gone to the wall.

The advent of the Industrialised Housing boom in the U.K. resulted in a large number of systems being developed or bought in, most of which vanished rapidly. On the large panel precast concrete side some of the major contractors (who normally did cast in place work) bought in systems, one result being the ill-fated Ronan Point. The successful operation of such a system requires (a) an effectively designed and detailed system of construction, (b) an adequate market, and (c) a competent organisation - which of necessity requires a sales force in contact with clients, a design and detailing team, and finally manufacturing and erection organisations. When the housing market was present, success depended very much on the solid back up of an efficient organisation, and 'buying in' of systems was not a panacea for an ill-equipped organisation.

44 industrialized concrete construction

In the U.K. the present position with regard to other structural precast concrete firms can be summarised as follows :-

- (a) Flooring: there is a multiplicity of firms who operate in a small or medium way generally in localised areas. Many of these firms manufacture architectural concrete and other products.
- (b) Portal and other industrial frames: there are basically three or four firms who specialise in this and cover the bulk of the country; in general these aim for standardised production; one firm in particular specialises in the unusual "one off" approach.
- (c) General multi-storey frames: three or four firms having a medium sized operation akin to that of Concrete Limited.
- (d) Industrialised Housing: apart from one precast firm now essentially operating only in Scotland, these are down to about three major poured in place contractors who have "bought in" systems; present operations are minimal.

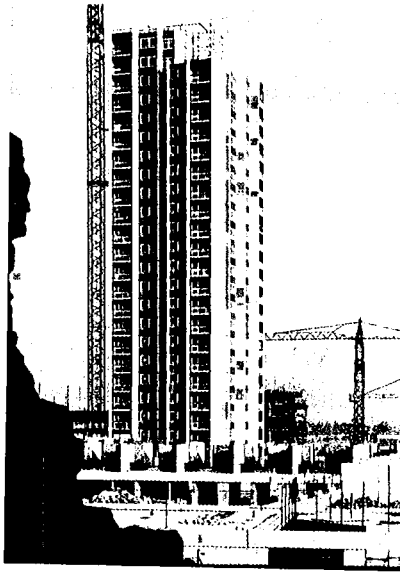
RECENT TRENDS IN THE MARKET

1. Housing

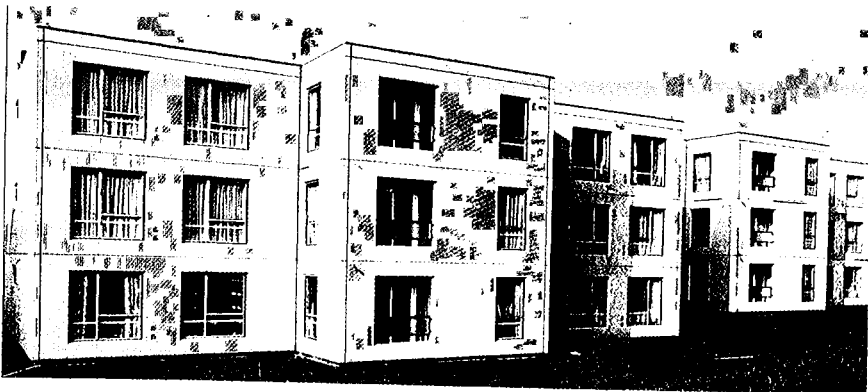
The boom that hit the industrialised building industry about 1964 primarily came about following the then U.K. Labour Government's policy for public sector (socialised) housing - a completely different environment from most of the U.S.A. A considerable part of this market comprised essentially tower blocks in the range of 10 - 24 storeys, which apart from ground level and roof, gave repetition at each floor; in the particular economic climate, large panel construction utilising structural concrete walls for room separation within dwellings was by far the most economical solution; a follow up of this, (essentially a change in architectural fashion), were the "deck access" blocks usually in the region of 5 - 8 storeys, containing dwellings on one and/or two levels, with decks at basically every third level, capable of light traffic such as milk delivery vehicles, with suitable link bridges between blocks.

Material disadvantages of this access form of construction include

- a) Construction is spread over the site and not concentrated - increasing costs of "getting out of ground" and also craneage - in the U.K. static or semi mobile tower cranes have substantial cost advantages.



Wall Frame Flats, Greenwich, London. One of seven blocks built in 1968 showing excellent architectural handling of precast concrete. The award winning Bison block built by Strecon Industries at Delaware University

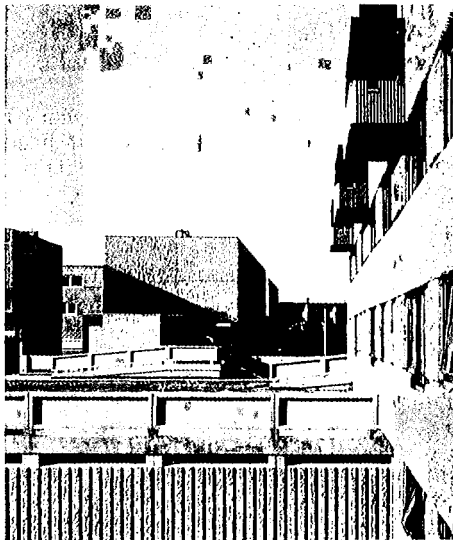


Three story Wall Frame Flats, Hillingdon, London, 1970

46 industrialized concrete construction



Wall Frame Flats, Birmingham 1964/65. Standard blocks adequately spaced to blend with the surroundings



Concrete jungle, lowrise deck access blocks of high density. Elevated access decks can be seen in the center and the left, and they have been given walk names, built in 1966. This type of planning can produce massive problems



An unwieldy attempt to get character into a lowrise deck access development. Access decks junctions are clearly visible in right center of the picture, built in 1971

48 industrialized concrete construction

- b) The tendency to have series of blocks linked by bridges often meant the every "link" was different - on one major contract 37 links occurred, and each was different due to different lengths between and alignment of blocks, different services in the links (stairs, passenger lift, goods lift), and to changes of ground level. Not only would the links be different, but they would affect the ends of the blocks concerned, causing variations in units. On one preliminary scheme for some 1000 dwellings which the author personally considered, a particular unit occurred only three times, and three further times in a handed (mirrored) form - and the units would have probably been required at three monthly intervals; this type of thing ruins all the advantages accruing elsewhere.
- c) Deck access jobs meet difficulty in trying to accommodate too many different types of dwelling in the same block. Coping with a two storey apartment above a single storey one, including an access deck, is bad enough when trying to keep cross walls vertically in line as well as maintaining apartment sizes to those specified, but then trying to put in the same block a similar but, say, larger pair of apartment along side - this just makes nonsense of industrialised and rational construction.
- d) External access decks create problems whether they cantilever out or are internally contained in a walkway which is within the structure but open to the atmosphere. One is waterproofing, which does call for careful consideration, detailing and execution of work - a specific point is usually the deck slabs have to be substantially shallower to give waterproofing and falls to the deck and to keep this below apartment floor level. A second problem, which can be much more difficult to cope with in certain conditions is that of "cold leak". The deck being open to the atmosphere can get extremely cold, and inevitably its structural support is the structure of the apartment; in conditions where structural concrete is decorated direct and where the apartment is intermittently heated the circulation of warm air of high humidity will almost certainly cause considerable condensation on a surface which is incapable of absorbing moisture. The third serious problem is that of sound - the transmission of impact noises is worst when a deck is directly over an apartment and it is extremely difficult to have to deal with a light delivery vehicle moving on a deck over a bedroom - in the early hours of the morning!

Many of these problems are probably not relevant in the U.S.A., where the type of design with which our Licensees have been involved have avoided the absurdities of the deck access concept and this coupled with close carpeting and a reasonable minimum level of overall heating has eliminated the problems of impact sound insulation and condensation.

Unfortunately, in the U.K. a number of pressures have substantially reduced the construction of medium and high rise dwellings - which has knocked the bottom out of this market for industrial large panel construction. The general current trend is for two-storey houses and the present Conservative Government has reduced the support for the socialised housing - two factors weighing heavily against industrialised concrete construction. Two-storey dwellings have been built in large concrete panel construction, but at the moment there is much more competition from traditional building and/or industrialised timber or other forms of construction, although the present upward trends in world timber prices, coupled with the shortage and cost of bricklayers, are both factors advantageous to precast concrete. It is difficult to provide accurate information without getting extremely detailed but the following table derived from a publication of the Government Statistical Service shows the falling off of housing since 1968, the substantial drop in the public sector, and its catastrophic affect on industrial housing.

COMPLETED DWELLINGS
ENGLAND AND WALES

	Public Sector	Private Sector	Total	Industrialised Buildings (2)
1967	169,958	192,940	362,898	49,049
1968	158,453	213,273	371,726	50,569
1969	150,788	173,377	324,165	53,150
1970	145,182	162,084	317,266	55,701
1971	129,778	179,998	309,776	38,314
1972 [*]	95,100	182,000	277,100	24,000

(1) ^{*} Precise data available for 9 months. Figures given estimated from trend.

(2) This includes industrialised timber houses, etc.

As regards the future, in the author's view there will be an inevitable return to high rise construction for city centres, which will fluctuate as pressures dictate, but will be unlikely to approach the volume of construction of the middle sixties.

50 industrialized concrete construction

Whilst the prime use of large panel industrialised construction has been housing, there are associated usages - any buildings which serve as dormitory (sleeping) accommodation have a cellular requirement ideal for panel construction. Typical examples are hotels/motels, hospital(staff) or university dormitories, and even prisons. Whilst these are secondary to basic housing, they are of commercial interest; in the U.K. it seems unlikely that much further university accommodation will be provided, but both hospital staff accommodation and the replacement of prisons appear to be possible areas of growth.

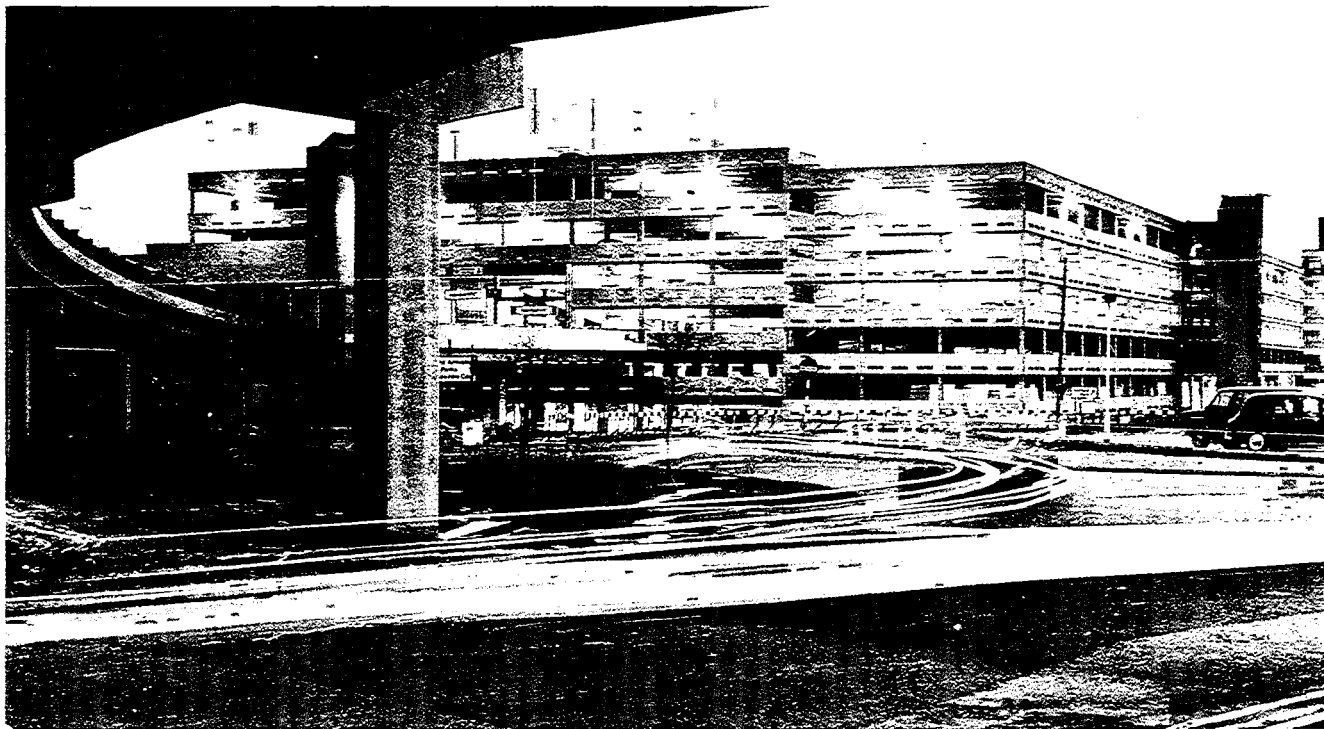
2. Multi-storey Car Parks.

Concrete Limited has been building clear span parks using pretensioned beams on an industrialised concept for many years, but is virtually the only firm which is selling an industrialised precast concrete approach; serious competitors using an industrialised approach are poured in place - lift slabs (a solid deck sometimes "warped") and waffle or ribbed slabs, which are based on standard formers. In general, the clear span pretensioned beam approach is of the same order of cost as the lift slab and waffle, both of which have interior columns, and is usually cheaper than the clearspan poured in place ribbed.

The choice of whether an industrialised approach is used or not depends usually on the form the contract is let - normally when a client issues a performance specification and invites tenders, the result is a system design, whereas if he does not, it will be a "one off" design, some of which have copied the Bison approach, and quite a number utilise Bison floors.

Studies of the Bison Mark II design have been carried out over the years; technically (and costwise) it appears to remain an extremely effective solution; recently, with the advent of metrication and the Unified Code further studies were carried out and a Mark III design was developed from it - but, whilst this offered advantages, including cost, the capital cost of moulds resulted in the Mark III being shelved until mould replacement was necessary.

In the U.K. there appears to be little doubt that Multi-Storey Car Parks offer plenty of scope for the present and future, and we normally use clear span precast designs; it is of course essential that the elevational treatment should be flexible - as should be the ability to provide flat decks, split level or parking ramps.



Manchester Airport Car Park/Booking Hall 1973. The parking structure holds 2000 cars, and is about 80th built to a standard design concept, elevations being modified to suit each requirement