

# RESEARCH REPORT



## Proof of Concept: Development and Testing of the Biocrete House Construction System



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**Proof-of-Concept**  
**Development and Testing of**  
**The Biocrete House Construction System**

**Internatural Canada**

**March, 1996**

This project was carried out with the assistance of a grant from Canada Mortgage and Housing Corporation under the terms of the Housing Technology Incentives Program. The views expressed are those of the author and do not represent the official views of the Corporation.

## **Foreword**

The following report was prepared by Scanada Consultants Ltd., an independent third party consulting engineering firm, for Internatural Canada. The report outlines the final results and conclusions of our project for “Proof-of-Concept Development and Testing of the Biocrete House Construction System”. The results of this project highlight the technical strength of our Bioblock/Biocrete building materials and technology and help to confirm the commercial potential of our building system.

Internatural Canada’s success to date, and for the future, has been supported by a large number of people. We thank them all for their help. In particular, we would like to thank the following organizations and people for their support for and influence upon the current project.

Wittold Weyneroski has been a long time supporter of our efforts. He commissioned our initial prototype building structures erected on his property in Wakefield, Québec. These prototypes showed that our ideas were valid, taught us important engineering lessons and pointed the way towards the proof-of-concept testing project.

Ross Monsour of the Canadian Home Builders Association supported the project from the outset and has remained keenly interested in our progress.

CMHC’s support through the Housing Technology Incentives Program (HTIP) was critical. An HTIP grant provided the funding which enabled us to proceed with and complete our proof-of-concept testing. As well, the professional contribution made by CMHC’s Research Division, in particular, Al Houston and Michael Macpherson, has been valuable in helping to redefine our concepts and develop our business plan.

Bob Platts and his colleagues at Scanada Consultants Limited played a key role in the success of this project. Their ideas, enthusiasm and dedication of time beyond that which could be funded through our HTIP grant helped us to improve our building system and complete the project.

In the report, mention is made that the production and testing facility used in Phase II of the project was a neighbour’s barn/workshop in Wakefield. We thank our neighbours, Henry Zwanenberg and Nicole Lévesque, for their generous support to this project and their patience with us during the production and testing periods of the project.

Additionally, Internatural has benefited from the work of many previous and current researchers and builders. Our Bioblock/Biocrete building system builds upon methods, mixing clay with plant or other material, used for centuries in other countries. Centuries-old adobe pueblos in the southern United States attest to the longevity of these building methods. Our ideas have been greatly influenced by research into the straw-bale and mortar houses of Louis Gagné of Wakefield, Québec, ongoing research in the American Nebraska system and the works of Christopher Alexander and Ken Kern of California.

Moving into the future, our vision for Internatural Canada remains clear: to provide affordable, quality building materials and technologies worldwide that improve the environment. We are now moving quickly to put our vision into action. Our first step is the preparation of Internatural Canada's business plan for 1996-1998. In preparing our business plan, we are addressing a number of key questions:

- where and what are our potential markets?
- how do we compare in terms of cost / performance / market acceptance with existing and new alternatives in these potential markets?
- what should be our overall business strategy for the next three years, and what should be our particular areas of focus during 1996?
- what specific initiatives and targets will we set for 1996?

These questions arise naturally from the success of our proof-of-concept development and testing. They also mean that we will be focusing our priorities upon business, marketing and operational challenges, as well as engineering and technical ones.

We welcome your comments on this report.

Brad Robinson  
President  
Internatural Canada

**PROOF-OF-CONCEPT DEVELOPMENT AND TESTING OF  
THE BIOCRETE HOUSE CONSTRUCTION SYSTEM**

Report by

**Scanada Consultants Limited**  
R. E. Platts, P.Eng.

for

**Internatural Canada**

Ottawa, January 1996

## **ACKNOWLEDGEMENTS**

When Scanada was asked by the Internatural people to provide the engineering for their Biocrete R&D project, it quickly became apparent that Internatural already had a significant technical capability. Scanada is delighted to acknowledge the seminal and crucial role of the Internatural people, and most particularly the contributions of ideas, insights, invention and fabrication skills, and just dogged hard work, on the part of Brad Robinson and Louis Rompré.

## **ABSTRACT**

Turning "waste" organic fibre such as forest and construction wood wastes into sound, affordable housing is an attractive idea. Using just such wastes, Internatural Canada has demonstrated successfully that their "Bioblock-Biocrete" concept can readily produce exterior walls that are technically sound and should offer very low costs; further, the concept could well be extended to produce vaulted wall-roofs comprising much more of the house envelope. The Internatural team developed a production approach and prototype "blockmaker" for producing dry-compacted "Bioblock" composites; produced a viable variety of prototypical Bioblocks, primarily using shredded forest canopy and construction lumber wastes for proof-of-concept purposes; built structural sandwich walls (using just unreinforced cement-lime stucco to substitute for the variety of soil-fibre-cement "Biocrete" skins that are attainable); and structurally tested the components and the whole. The work and results also afforded insights into production, construction and cost considerations and has encouraged Internatural to proceed toward full development and commercialization.

## SOMMAIRE

Construire des logements solides et abordables avec de la fibre organique destinée au rebut, comme les résidus de bois de construction et d'exploitation forestière, est une idée intéressante. Avec de tels résidus, l'entreprise Internatural Canada a démontré que son concept de « biobloc-biobéton » (Bioblock-Biocrete) peut facilement produire à très bon marché des murs extérieurs solides. En outre, on pourrait pousser plus loin ce concept pour produire des toits en voûte et inclure ainsi une plus grande partie de l'enveloppe du bâtiment. L'équipe d'Internatural Canada a élaboré une méthode de production et un prototype de « machine à blocs » (blockmaker) afin de produire des composites de « bioblocs » compactés à sec; elle a produit une variété viable de bioblocs types fabriqués essentiellement avec du couvert forestier déchiqueté et des résidus de bois de construction pour effectuer un essai de validation; elle a bâti des murs sandwich (en utilisant uniquement du stucco bâtard non armé pour remplacer toutes les combinaisons possibles de revêtements en « biobéton » à base de terre, de fibre et de ciment); enfin, elle a soumis à des tests structuraux les composantes et le système des murs. Les travaux et les résultats donnent un aperçu des préoccupations touchant la production et la construction ainsi que des coûts qu'il faudra envisager et encouragent Internatural Canada à mener jusqu'au bout le développement et la commercialisation de son produit.

## EXECUTIVE SUMMARY

The concept of producing affordable housing from waste materials may sound too good to be true, especially if the wastes are mostly organic fibre, such as forest or construction wood fibre, presently burned or buried in vast quantities. Using just such wastes, however, Internatural Canada has demonstrated in this project that their "Bioblock-Biocrete" concept can readily produce exterior walls that are technically sound and should offer low costs. Further, the concept could well be extended to produce vaulted wall-roofs comprising much more of the house envelope. This concept is a strong part of the original Biocrete vision.

The Internatural team has completed its proof-of-concept work much as planned and proposed to the sponsor, the Canada Mortgage and Housing Corporation. In this first pioneering project, the team has successfully:

- Selected wood fibre and other wastes as presently dumped in crudely shredded form - good fibre but in a very cheap "worst case" form. **Photos 1 and 2** illustrate the point.
- Developed a manufacturing approach and prototype "blockmaker" for producing dry-compacted "Bioblock" composites, in which the predominant lie of the fibre is transverse to the length of the block to produce the desired physical properties. **Photos 2 and 3** show some of this. (Not shown are some key solutions for which patent protection should be sought.)
- Produced a viable variety of prototypical Bioblocks, using mostly shredded forest canopy and construction lumber wastes for proof-of-concept purposes; **Photos 4 and 5**. (A straw block sample was produced for comparative purposes, exploring the range of fibre stock amenable to the blockmaker process. Shredded polyethylene was included in some sample blocks to explore the ability to add non-fibrous wastes without unduly diluting physical properties of a Bioblock system.)
- Built structural sandwich walls (using just unreinforced cement-lime stucco to substitute for the variety of soil-fibre-cement "Biocrete" skins that are attainable); **Photos 6 to 10**.
- Structurally tested the components and the wall system, **Photos 11 to 15**, with results as shown in **Figures 1 to 8**. The test program helped characterize both the prototypical Bioblock in terms of unit physical values as needed for final composite (structural sandwich) design, and prototypical structural sandwich walls.

The prototyping of components and assemblies also afforded insights into production, construction and cost considerations, including construction methods, and stability and safety issues before the structural skins are applied and cured.

The costs of test facilities, set-up and engineering to complete the project were clearly far beyond the modest HTIP budget. However, the project became feasible because of opportune "networking": 1) a neighbor opened her barn/workshop facility to Internatural's use at nominal cost, along with power and an ample selection of building materials; 2) a separate system developer - Linda Chapman Architect - needed a working area and identical structural test gear to proceed with HTIP R&D on her "Prestressed Nebraska" strawbale house wall system, and shared the costs accordingly; and 3) much of the Scanada engineering - load calculations, test requirements and methods, analyses - was common to both systems and these costs were also shared between the HTIP projects.

Even at this first prototype stage - more akin to mock-up than prototype in several aspects - the system's overall structural and general feasibility for housing production has been demonstrated successfully. Stiffness and strength were shown to greatly exceed that of common wood frame construction. No crucial drawbacks are seen. Immediate opportunities for improvement are clear: mesh choices for lower cost, the types and application methods of the Biocrete skin, and the size and shape of particles used in Bioblocks to achieve better thermal values. Detailing to avoid moisture accumulation and ensure durability will be vitally important. As well, it will be necessary to ensure that issues such as fire propagation characteristics are addressed.

Internatural Canada is encouraged to pursue its goal of full R&D and deployment of the Biocrete alternative that, at the least, appears able to turn "waste" wood fibre into house walls that complement North America's wood frame house structures, and potentially offers indigenous material choices and housing solutions to much of the developing world.

## RÉSUMÉ

Construire des maisons abordables avec des résidus est un concept qui semble trop beau pour être vrai, d'autant plus que ces résidus se composent surtout de fibre organique, comme la fibre de bois de construction ou de forêt que l'on brûle ou enterre en grandes quantités. Avec de tels résidus, Internatural Canada a mené un projet ayant démontré que son concept de « biobloc-biobéton » peut facilement produire à bon marché des murs extérieurs solides. En outre, on pourrait pousser plus loin ce concept pour produire des toits en voûte et inclure ainsi une plus grande partie de l'enveloppe du bâtiment. Ce concept est né en grande partie de la vision originale de fabriquer du biobéton.

L'équipe d'Internatural Canada a terminé son essai de validation à temps et comme elle l'avait proposé à la Société canadienne d'hypothèques et de logement, qui a parrainé le projet. Dans ce premier projet innovateur, l'équipe a réussi à :

- trier la fibre de bois et d'autres résidus tels qu'on les jette, sous forme de matière brute déchiquetée - il s'agit de fibre sous sa pire forme mais encore utilisable et à très bon marché. Les **photos 1 et 2** illustrent ce point;
- élaborer une méthode de fabrication et un prototype de « machine à blocs » permettant de produire des composites de « bioblocs » compactés à sec dans lesquels la couche principale de fibre est transversale à la longueur du bloc afin d'obtenir les propriétés physiques voulues. Les **photos 2 et 3** illustrent une partie de ce concept. (Les solutions clés n'y apparaissent pas pour des motifs de protection par brevet.);
- produire une variété viable de bioblocs types fabriqués essentiellement avec du couvert forestier déchiqueté et des résidus de bois de construction pour effectuer un essai de validation (**photos 4 et 5**). (Un échantillon de bloc de paille a été fabriqué à des fins de comparaison et pour déterminer les diverses fibres se prêtant à la fabrication de blocs à l'aide de la machine à blocs. On a placé dans les blocs-échantillons du polyéthylène déchiqueté pour étudier à fond la possibilité d'ajouter des résidus non fibreux sans affaiblir excessivement les propriétés physiques du système de bioblocs);
- construire des murs sandwich (en utilisant uniquement du stucco bâtard non armé pour remplacer toutes les combinaisons possibles de revêtements en « biobéton » à base de terre, de fibre et de ciment). Se reporter aux **photos 6 à 10**;
- soumettre à des tests structuraux les composantes et le système des murs (**photos 11 à 15**). Les **figures 1 à 8** illustrent les résultats des tests. Ce programme de tests a permis d'établir les caractéristiques du biobloc type, telles que les valeurs physiques unitaires nécessaires à la conception finale du composite (structure sandwich) et les murs structuraux sandwich types.

Le prototypage des composantes et des assemblages a également donné un aperçu des préoccupations touchant la production et la construction, des coûts qu'il faudra envisager, des méthodes de construction et des questions de stabilité et de sécurité qu'il faudra aborder avant d'appliquer et de faire sécher les revêtements structuraux.

Les coûts associés aux installations d'essai, au montage et à l'ingénierie pour mener à terme le projet ont grandement excédé le modeste budget que le Programme d'encouragement à la technologie du bâtiment résidentiel (PETBR) nous a accordé. Cependant, nous avons pu réaliser notre projet grâce aux participants qui sont venus à notre secours au moment opportun :

- 1) une voisine a offert sa grange aménagée en atelier à l'équipe d'Internatural à peu de frais, électricité comprise, et beaucoup de matériaux de construction;
- 2) Linda Chapman, architecte et spécialiste en réalisation de systèmes, qui avait également besoin de cette atelier et des outils s'y trouvant pour effectuer des tests structuraux sur des murs en bottes de paille « précontraintes Nebraska » dans le cadre de son projet de recherche et développement parrainé par le PETBR, a partagé les frais avec Internatural;
- 3) la plupart des travaux d'ingénierie de Scanada - calculs des charges, méthodes et spécifications d'essai, analyses - devaient être effectués sur les deux systèmes, et les coûts y étant associés ont également été partagés entre les partenaires des deux projets du PETBR.

Même à ce premier stade de prototypage - le prototype ressemblant plus à une maquette à plusieurs égards - nous avons pu montrer qu'on peut utiliser la structure du système dans l'ensemble pour bâtir des logements. La rigidité et la solidité ont même dépassé celles des charpentes en bois que l'on construit couramment. Nous n'avons observé aucun inconvénient grave. Cependant, nous pourrions nettement améliorer le système par du treillis à meilleur marché, des types et des méthodes d'application de revêtement biobéton ainsi que par la taille et la forme des particules utilisées dans les bioblocs pour obtenir un meilleur rendement thermique. Il est également primordial de déterminer comment éviter l'accumulation de l'humidité et assurer la durabilité. Il faudra en outre se pencher sur certaines questions, telles que les caractéristiques de propagation du feu.

Encouragée, l'entreprise Internatural Canada poursuit son objectif de mener jusqu'au bout le développement et la commercialisation du biobéton comme solution de rechange, qui du moins pourrait transformer les résidus de fibre de bois en murs de maison, s'ajouter aux techniques nord-américaines de construction à ossature de bois et offrir des choix de matériaux indigènes et des solutions de logement à une grande partie du monde en pleine évolution.



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## 1. INTRODUCTION

This report presents the results and findings of Internatural's pioneer research and development project to its sponsor, Canada Mortgage and Housing Corporation's "HTIP" program — the Housing Technology Incentives Program. Internatural Canada was formed to harness and develop a simple idea: that good housing can be produced from organic fibre wastes, wood fibre in particular. Vast quantities of such wastes pose an enormous disposal and pollution problem; the need for quality, affordable housing in vast numbers remains an enormous problem as well. Internatural has proposed that the disposal problem can be inverted completely, with cast-off fibre becoming "feedstock" to help meet housing needs and resolve both problems.

When the engineering R&D team was first being brought together, the "Biocrete" idea had already been conceived and pursued as a soil-cement-bonded matrix of waste wood fibres and other shredded scrap materials, site-cast as a wet slurry. In trials, the matrix was cast and cured to form a stressed skin sandwich composite in which strong, high-density "skin" zones graduated to a weaker, low density insulating/stabilizing core. In this early work - and still in the longer vision - the idea was to form the composite into an arched or vaulted structure comprising much more of the house envelope than just the exterior walls.

Recognizing that the site-mixed site-cast slurry approach to constructing the Biocrete envelope is rife with potential difficulties (in proportioning materials, avoiding contaminants that inhibit curing, assuring curing in colder seasons and avoiding excessive moisture and its entrapment), Internatural's team favoured a simplified alternative, the **Biocrete/ Bioblock** approach. In this the core matrix would be produced as large building blocks, "Bioblocks", in a factory or mobile plant under controlled conditions. Stacked dry, the block walls would then be finished each side with wet-applied Biocrete as structural skins to complete the wall. This could be done in shotcrete fashion, for example.

The potential benefits of Internatural's "Biocrete/Bioblock" idea are broad and deep; the beneficiaries are people who need housing, the forest industry and all parties concerned about the environment and sustainable production within it. In this project, the company's engineering team has explored, shaped and reshaped and proof-tested the Biocrete/Bioblock idea, demonstrating that it is technically feasible and that it appears economically promising.

## 2. THE BIOCRETE/BIOBLOCK WALL SYSTEM

The Bioblock was first conceived as a soil-cement-bonded fibre composite. The team soon stripped the whole approach down to a simpler, more producible concept: the Bioblock concept became a dry-compacted or baled block of shredded biomass, cement-free, tightly constrained with a mesh or net. The net would also serve to further lock in and reinforce the applied Biocrete skins, to ensure full stressed skin or structural sandwich action (the terms are synonymous in the present context). The concept was now somewhat analogous to the Nebraska strawbale type of

*Biocrete Proof-of-Concept Testing*

composite wall structure, but with a broadened "feedstock" and a whole new set of fibre meshing and block-making challenges.

The Internatural team narrowed the prototype system still further, thereby permitting a necessarily modest project to prove the concept and to structurally characterize a basic, practical composition. The Biocrete "skins" of the sandwich were to be - and ultimately may be - of densely matrixed soil-cement-bonded organic fibre, perhaps largely wood fibre. Literature reviews showed rather extensive work on organic fibre-cement composites, with somewhat discouraging findings on durability problems. This HTIP project could scarcely evaluate all the existing work, let alone attempt to carry it further. In order that the Bioblock-cored sandwich could be formed and evaluated as a simple, practical composite, the team decided to rely on known lime-cement stucco skins. Neither fibre-reinforced nor otherwise high-performance stuccoes was used at this point, although such formulations are commercially available and well proven. The prototypical system is described in more detail as the work and results are next reported.

### 3. METHODOLOGY

The goal of the project was to complete a proof-of-concept demonstration of the potential reproducibility and structural capability of a dry-compacted Bioblock sandwich wall concept. Our methodology involved the following steps:

- potential Bioblock compositions were determined, of which a limited few were selected for proof-of-concept purposes;
- a "working mock-up" blockmaker was designed and fabricated;
- the blockmaker was used to produce the selected variety of Bioblocks in sufficient numbers for individual block and assembly testing;
- the apparently viable samples of Bioblocks were structurally tested; and
- the Biocrete/Bioblock concept was demonstrated as a structural wall by building and testing full structural sandwich prototypes.

The Internatural team undertook all of this afresh, occasionally drawing upon existing knowledge, parallel work and standard test methods and criteria, whenever applicable, but often mostly deriving tools, methods, compositions, tests and evaluation criteria within the team.

**Production and testing facility:** One of the main challenges was to set up a "factory" in conjunction with a rather complete test facility, since the wall assemblies are too heavy and awkward to move to a lab and must be tested in-situ. The costs of such a facility, set-up and engineering were clearly far beyond the modest HTIP budget, but the job became feasible because of opportune "networking": 1) a neighbor opened her barn/workshop facility to Internatural's use at nominal cost, along with power and an ample selection of building materials; 2) a separate system developer - Linda Chapman Architect - needed a working area and identical structural test

#### *Biocrete Proof-of-Concept Testing*

gear to proceed with HTIP R&D on her "Prestressed Nebraska" strawbale house wall system, and shared the costs accordingly; and 3) much of the Scanada engineering - load calculations, test requirements and methods, analyses - was common to both systems and these costs were also shared between the HTIP projects.

**Bioblock production and testing:** The production of prototype or "mock-up" Bioblocks is described below. The intent of structural testing of the individual blocks was to characterize them as core elements of structural sandwich composites; Scanada defined the useful types and degrees of stress-strain testing. Such properties are best tested on commercial Instron machine and Tinius Olsen machines - and the blocks proved to be light and tough, easily carried to a structural lab. Dr. Razaqpur agreed to conduct the prescribed tests in Carleton University's structural lab, again at a very reasonable cost. Details are given below, with the test results.

**Wall system testing:** The engineers drew upon housing engineering work and particularly stressed skin-structural sandwich R&D from the 1950s on, to help define and devise the test rigs and criteria as well as the prototypical system itself. As noted below, the rigs were built to outdo the Instron machine in one important respect, allowing vertical loading simultaneously with transverse horizontal loading - the first, hydraulically with jacks and Carleton's electronic load cells and digital oscilloscope readout, the second pneumatically through purpose-made airbags. Vertical and horizontal deflections were measured to the nearest millimetre.

#### **4. DEVELOPING PROTOTYPE BIOBLOCKS**

While Bioblocks and, to a lesser extent, Biocrete will be highly variable in structural properties — and this is not a great disadvantage in such house system development — it was necessary to bracket a tight range of characteristics for proof-of-concept purposes. The team decided that mixes of shredded forest canopy fibre (or construction wood wastes) "diluted" to varying degrees with shredded polyethylene can be used as proxies for perhaps any practical mix of waste materials. The prototypical compositions were chosen as follows, graded by anticipated stiffness/strength qualities:

- a) a best case mix of shredded forest canopy and construction waste (pallets), quality "Qa",
- b) an intermediate mix in which considerable bark, fines and shredded brush were included...Qb,
- c) a worst case mix of a substantial proportion of shredded polyethylene mixed with the shredded wood...Qc.
- d) A block of wheat straw - a proven fibre in rather analogous constructions — was also produced for comparative purposes.

#### ***Biocrete Proof-of-Concept Testing***

The concept stays away from any type or degree of defibration process that relies on chemical refining of feedstock or intensive, energy-consuming mechanical defibration; chopper and/or shredder processing is considered appropriate.

Considering lumber or forest canopy wastes, the chopped/shredded pieces tend to be relatively short and thick rather than fibrous, chip or strand in form, **Photos 1 and 2**. Such shapes do not pack easily nor do they present much surface area to develop friction with each other. The Scanada engineers suggested that a transverse orientation - akin to baled straw but with the chunks running vertically as well as horizontally through the depth and width of the block - is ideal to allow the friction-bound pieces to maintain a rectilinear block shape under handling and loadings.

Reviews of waste compactors and straw balers - including the patent literature failed to uncover any "blockmaker" device that could handle the stubby chunks and wafers and orientate them properly. The team began afresh, developing a blockmaker that:

- allows gravity to arrange the pieces transversely through the depth and width of the block;
- compacts the material inside a mesh jacket without distorting or ripping the mesh;
- develops and captures the necessary pressures, packing contacts and friction to produce a viable structural block - even with the far-from-ideal shapes.

**Photos 2 and 3** show the blockmaker in action. Some of the workings are considered proprietary and Internatural may seek patent protection. **Photos 4 and 5** show some of the prototype Bioblocks. (The mesh jacket obtained for the prototypes is apparently formed of polycarbonate, offering great strength but with a 0.75 x 1.125 in. grid that poorly retains the shorts and fines, and a price that defeats the concept. Equally strong but much finer grid mesh is used by cellulose insulators, for example, at a very small fraction of the price.)

Internatural did some lateral thinking as the blockmaker was taking shape: Peat Moss baggers must work much the same way. A transverse lie of the relatively fine, weak peat fibres must account for the remarkable box-shape integrity of the big blocks as they are stacked, trucked and handled. More to the point, the manufacturers of such bagger/compactors for peat moss and perhaps cellulose fiber should be able to advise on the feasibility of producing semi-automated versions of the Internatural rig. Accordingly, one manufacturer was invited to the Chelsea barn, and did confirm the feasibility.

## 5. STRUCTURAL CHARACTERIZATION OF THE BIOBLOCKS

Structural sandwich composites, as considered here, will be needlessly strong for house wall loadings as the dictates of dent resistance, fire resistance and insulation thickness override. To prove the point, structural testing of the components and the whole is nevertheless desirable. Looking ahead, structural characterization of the prototypical components is required to begin to anticipate design for seismic action and tornados, thin partitions and other components, 1-1/2 and two storey structures - and indeed into the vaulted shells where the Biocrete can realize Internatural's wider vision of providing most of the house envelope in one organic fibre system.

Structural sandwich design is a fairly well developed discipline where the skins are relatively thin and their stability against buckling or wrinkling depends determinably upon the elastic moduli of skin and core. That's the usual case in aircraft design and even in metal or other thin-skinned building components such as curtain walls; it is not so simple a case with the thick-skinned Bioblock walls. The thickness and structural capacity of Bioblock walls will be dictated by factors such as the R value that must be achieved. Core moduli are not so important, especially where transverse ties are present, as here, but the following properties are still needed for advanced design.

Carleton University's load/deflection testing on the Bioblocks is recorded in **Figures 1 to 7**. Unfortunately the lab did not record Internatural's identification codes, so that the compositions had to be deduced from the property ranking in most cases (marked \*). The results are summarized, always taking the Young's Modulus E from the initial part of the load/deflection curve, which is what's called into play in the composite. This is the main property defining the core's ability to stabilize the final skins under any type of panel loading, including concentrated denting loads. The properties may seem very low - about a quarter or less of those of 1 pcf expanded polystyrene, for example - but the structural sandwich stresses are very low as well. Further, the stabilizing of the skins, and perhaps the transfer of shear (diagonal tension) must indeed be aided greatly by the doubled mesh running transversely at 14 in. increments of wall height, where the jackets encase the blocks. Such functions need not be analyzed for present purposes, but they will have an influence.

- **Ect - modulus of elasticity in transverse compression** (through-wall direction)
  - \*wood chip Qa...231 psi
  - \*wood chip Qb....94 psi  
and 136 psi
  - \*wood chip Qc....50 psi  
- and straw...73 psi
- **Gv - the shear modulus of elasticity** - can not be coupon tested for such compositions, but may be assumed to be about one half of the Ect.

Other properties that may be considered for various design situations are:

- **Ett - modulus of elasticity in transverse tension.** Here, two blocks were faced with opposed tension plates, 7 in. square, adhered to the deeper fibre by polyester resin penetrating about 1 in. The idea is to characterize the tension modulus of the block proper, not its tension strength at its surfaces, by pulling apart a transverse section about 10 in. long and 49 sq. in. X-section. Only the initial part of the deformation curves (**Figures 1 and 2**) is significant, in that the mesh jacket sides begin to resist the tension load at appreciable deformations - much beyond those that a standing structure could use. (That's why the curves swing upward - the blocks stiffening - after substantial deformation, but that may only be of academic interest.)
  - wood chip Qa...54 psi
  - wood chip Qb...31 psi
- **Ecv - modulus of elasticity in vertical compression** - may be of interest where the wall's integrity after catastrophic failure of one skin is to be considered. In the Bioblock's "transverse random" fibre lie, where any side can be up, Ecv=Ect.

## 6. STRUCTURAL CHARACTERIZATION OF THE SANDWICH WALL

Type Qa Bioblocks were stacked two blocks long and seven blocks high to form two test panels of four feet by eight feet, 14 inches thick. The blocks were so firmly and precisely formed that the stacked panels stood by themselves (**Photo 6**). Wall construction operations could entail formwork or closely-spaced bracing.

Each panel was stuccoed with a very workable, moderately weak mortar mix: "Techmix" commercial premix, ASTM Type N, listing a 7 day compressive strength of 6.6 and 28 day 8.2 MPa, 50 mm cube (**Photos 7 to 10**). On the first panel, "plain stucco", the Bioblocks were simply rendered as stacked. On the second panel only, strips of the plastic mesh were tacked along each horizontal joint between the blocks before stuccoing, so that the skins were mesh reinforced top to bottom in this case. The rendering was remarkably well done, flat and smooth like a precast concrete panel. The stucco thickness was controlled to about one inch average in the first panel; better control in the second panel reduced the average thickness to about three-quarter inch. In both cases, about a quarter inch of the stucco was inside the mesh jacket and thoroughly surrounding and adhered to the Bioblock fibre.

The stucco skins were extended about a half inch beyond each end of the blocks — i.e., forming faces of 49 inches in overall breadth — to help compensate for the discontinuity effect of the skin at the vertical boundaries. The stucco was also pushed well into all joints between the panels and at the vertical edges, forming deep "fins", which would confuse the testing of the

composite as a pure sandwich panel. Nevertheless the testing was meaningful, particularly after the stucco tension skin was cracked.

**Photos 11 to 13** show some of the panel testing using the wall system test rig. As described in section 3 of this report, the test rig was built to permit vertical loading simultaneously with transverse horizontal loading. Vertical loading was accomplished hydraulically with jacks and Carleton University's electronic load cells and digital oscilloscope readout. Transverse horizontal loading was done pneumatically through purpose-made airbags. **Figure 8** gives the load/deflection results. Under vertical loading there was essentially no measurable deformation and so no curves to show, but all tests were instructive proof tests:

**1) Wall test 1 - plain stucco - vertical load only:**

Panel loaded uniformly along its top edge, essentially loading the stucco skins on their nominal

48 in. dimensions. Loading in steps to **2 storey design load x 2** **11,352 lbs.**

- No detectable buckling; skin shortening in height about 1 mm.

**2) Wall test 2 - plain stucco - wind load, plus full vertical:**

(Figure 8) Vertical load held at **2 storey design load** **about 6000 lbs**

Air bag "wind" load taken progressively to **wind design load x 4** **80 psf**

- Bending deflections as shown, to 2 mm; no detectable cracking or distress of any kind.

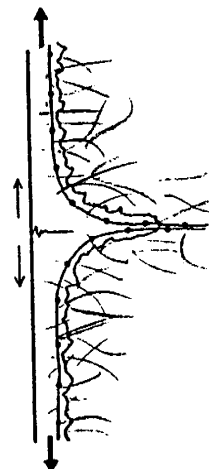
**3) Wall test 3 - plain stucco - wind load only (worst case, trying to break...)**

Vertical load of 136 lbs due to hydraulic jacks and the load plate.

"wind" load taken to same level, the limit of the first air bag **80 psf**

- Bending deflections as shown, to 5.2 mm since no vertical load was in play; still no detectable cracking or distress.

**4)** The test rig as built had now been taken to its groaning/air leaking limits, vertical and out-of-plane horizontal, with failure point and mode still not revealed. The stucco of this first panel was then sawn along the block joints, just short of the depth of the jacket mesh, and then cracked through by mallet and wedge. As shown in **Photo 15**, the mesh-in-stucco exhibits a surprising continuity across the joints despite the decidedly disjointed



configuration of the mesh as sketched.

#### 5) Wall test 4 - mesh reinforced stucco - wind load to failure:

Worst case loading, with no vertical load, and with new air bag capable of applying higher pressures. As shown in Figure 8, this second panel was stiffer than the first despite its thinner stucco, and was very strong and "failed tough".

- First, loaded to about **50 psf**
- Bending deflection as shown, to 0.5mm; no signs of cracking or distress.
  - Then to about **80 psf (3.74 kPa)**
- Bending to 1.5 mm; still no signs, but curve suggests plastic flow beginning...
  - Then to about **93 psf (4.48 kPa)**  
and on to **132 psf (6.35 kPa)**  
and holding load constant....
- Plastic flow first becomes apparent to testers following the 2.5 mm point, 4.48 kPa; tension skin cracks right across at about 6 mm as load is increased toward next reading at 5.33 kPa; stucco broke first about 400 mm from top, then breaks across at few more elevations, **Photos 14 and 15**. The first break, always the widest, appears to be mainly a flexure break due to the block deforming under compression or "punch shear" near and at the top restraint, but the stucco would also be under some tension and shear at that point. None of the cracking seemed to affect the load/deflection curve, suggesting that the mesh has been functioning as the essential tension skin even before visible cracking of the stucco.
- Perhaps the mesh's assumption of all tension accounts for the stiffening shown, above the 5 kPa level, but the load rate was not well controlled so not too much should be read into that. In any case, the plastic flow increased to the point that the load was simply held constant for two hours as shown, with bending continuing another 4 mm and the air bag distorting to its limit. The panel straightened halfway with the load removed, leaving a permanent set of 11.5 mm. The rig was not set up for resumption of vertical loading, but it was clear that the panel was still very strong in its "broken" state. The mesh-reinforced sandwich "fails tough", and only at loads of five to six times short-term design loads. Stiffness and strength greatly exceed that of common wood frame construction.

## 7. DISCUSSION AND CONCLUSIONS

First, some thoughts on the appropriateness and potential economy that seems unarguable in the generic approach manifested in Internatural's pioneer developments:

- There can be little argument about the superabundance of good quality wood fibre wherever there are forests — or, indeed, wherever there is industry. For example, one of the world's biggest disposers of "waste" wood fibre begging to be put to use is said to be General Motors... wood crates and pallets carrying incoming parts.
- The chain of collecting, transporting and even shredding the wood scrap is generally in place and working in any case, just for disposal purposes; incremental costs to divert the flow to Bioblock production sites could be small. Perhaps the biggest exception would be in the case of slash fire disposal of forest canopy fibre, where handling, shredding and drying would be extra costs in diverting the waste fibre into housing feedstock. But slash fire is obviously under attack, and the Bioblock alternative would stop it and greatly reduce the cut - increase the product yield per tree - at the same time.
- Production of Bioblock through an industrial version of Internatural's "blockmaker" could also be very low in cost. The process and the gear differ little from those that now bag peat moss or cellulose fibre in firmly box-shaped packages at a tiny fraction of the small total cost of production. The Bioblock plant could be central, regional, or village or project or mobile trailer in size and scope, to fit the supply point to the building site with minimal handling of the bulky blocks.

Next, back to Scanada's chief mandate in this project. It has been shown that the Bioblock process can readily produce complete house walls of ample structural capabilities for one or two storey houses, even using sub-optimal wood particle shapes and qualities. And it can do so with only moderate quality cementitious skins that are not supposed to take any tension, i.e., that lack the fibre reinforcing that Internatural's Biocrete approach would offer. With such fibre-cement skins or alternative mesh reinforcement (such as put to work in the second wall section) it is clear that the system is economically designable and producible to face severe hurricane or tornado and perhaps earthquake conditions.

Further, finer mechanical shredding of the wood fibre would could yield even better structural properties and certainly ample thermal resistance.

Finally, on the old and potentially critical moisture questions: 35 years of the writer's professional experience, together with theoretical analysis and recent computer modelling,

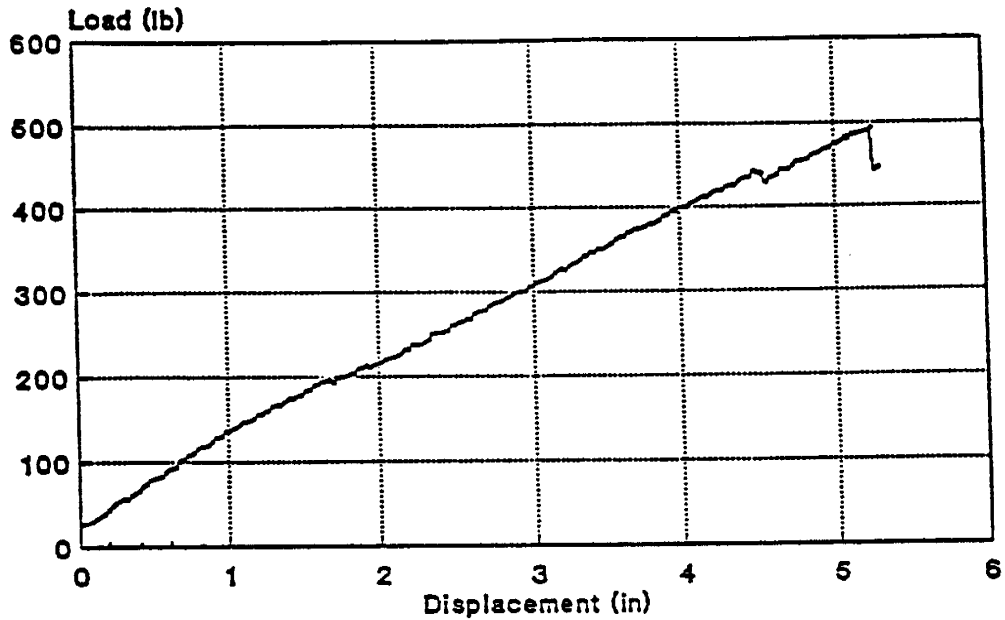
*Biocrete Proof-of-Concept Testing*

indicate that the Biocrete/Bioblock type of wall need have nothing to fear from vapour transfer and resulting condensation from indoor sources. Excessive condensate in house envelopes accrues only from through-leakage of indoor air - "mass transfer", never diffusion alone - and only where local leaks are large in relation to the envelope's storage capacity and entrapment characteristics. The Biocrete/Bioblock composite easily stays free of such weaknesses.

To clear the 1940's worries and building code residuals, an inner paint coating could be used and made a few times less water vapour permeable than an outer coating. That relationship was first recommended by the University of Illinois Small Homes Council in the early 1950s - either Professor Joy or Professor Queer - and generally costs little and does no harm... except where the wall is so wetted from outdoor sources that it needs the extra drying path to the indoors. The handling of outdoor moisture — precipitation, backsplash, ground moisture, standing water, wicking and draining action — is vitally important. Such organic fibre sandwich structures might not have the forgiving drain-dry capabilities that wood frame exhibits; that characteristic should be evaluated for the final composites. Design and construction detailing and care must respect the need to minimize water entry and avoid undue entrapment of moisture from any source.

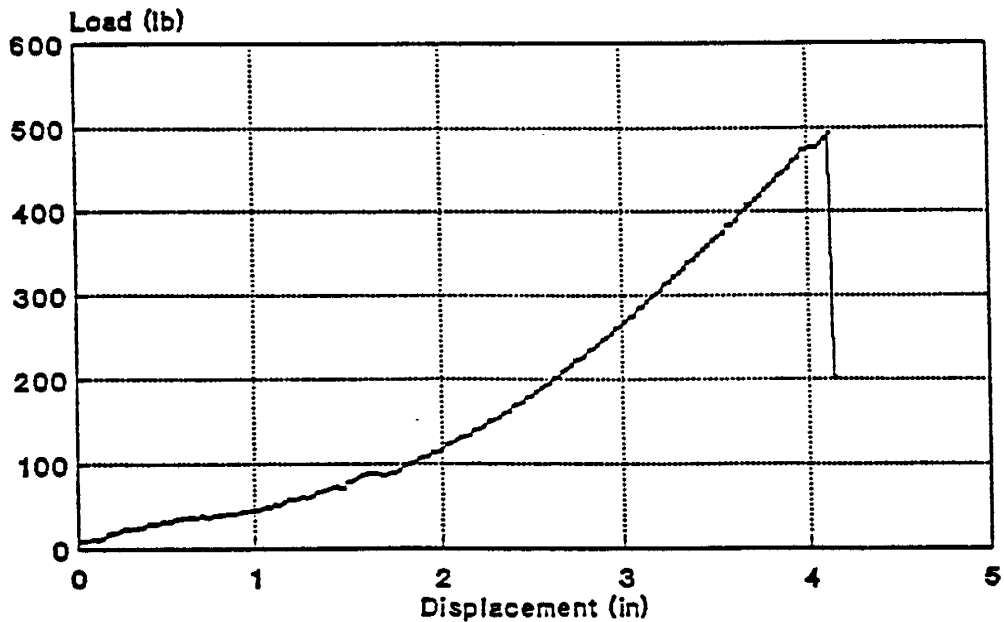
Scanada recommends that Internatural pursue its commercial goals. Potential champions that come to mind include companies such as MacMillan Bloedel and General Motors that must manage the disposal of their "waste" wood fibres.

(a) Initial Load Response



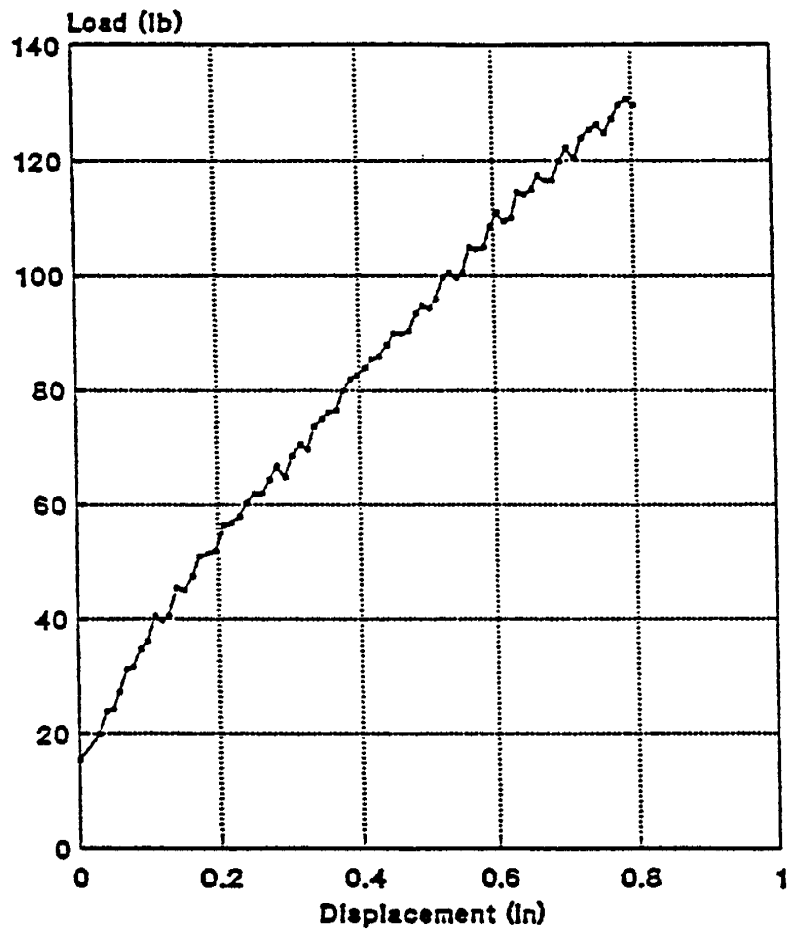
Tension Test of Bale  
Max load 498lb, Max Displacement 5.315in  
Rate of loading 0.1 in/min

(b) Reloading Response

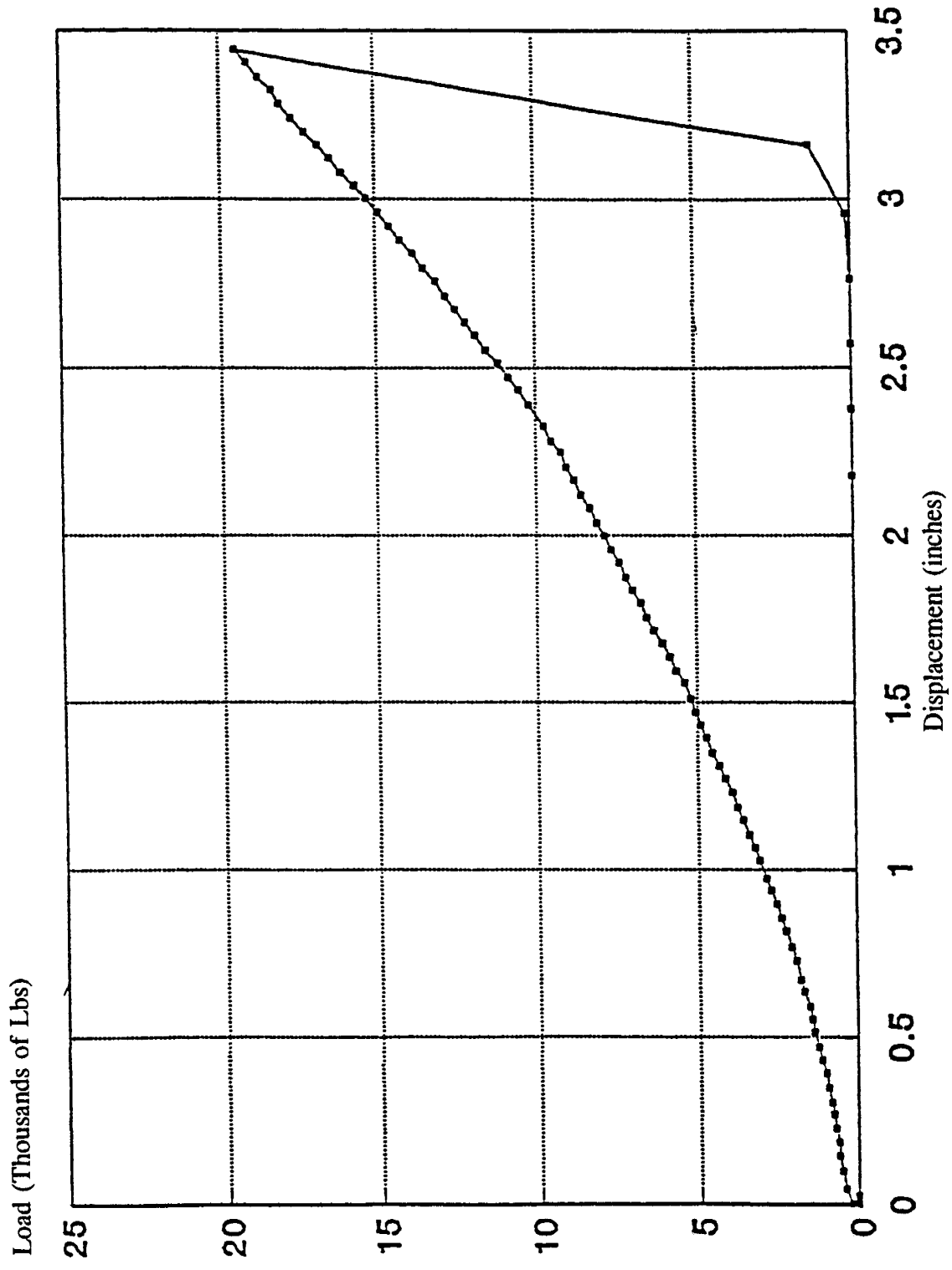


Tension Test of Bale 1: Reloading  
Max load 491lb, Max Displacement 4.117in  
Rate of loading 2.0 in/min

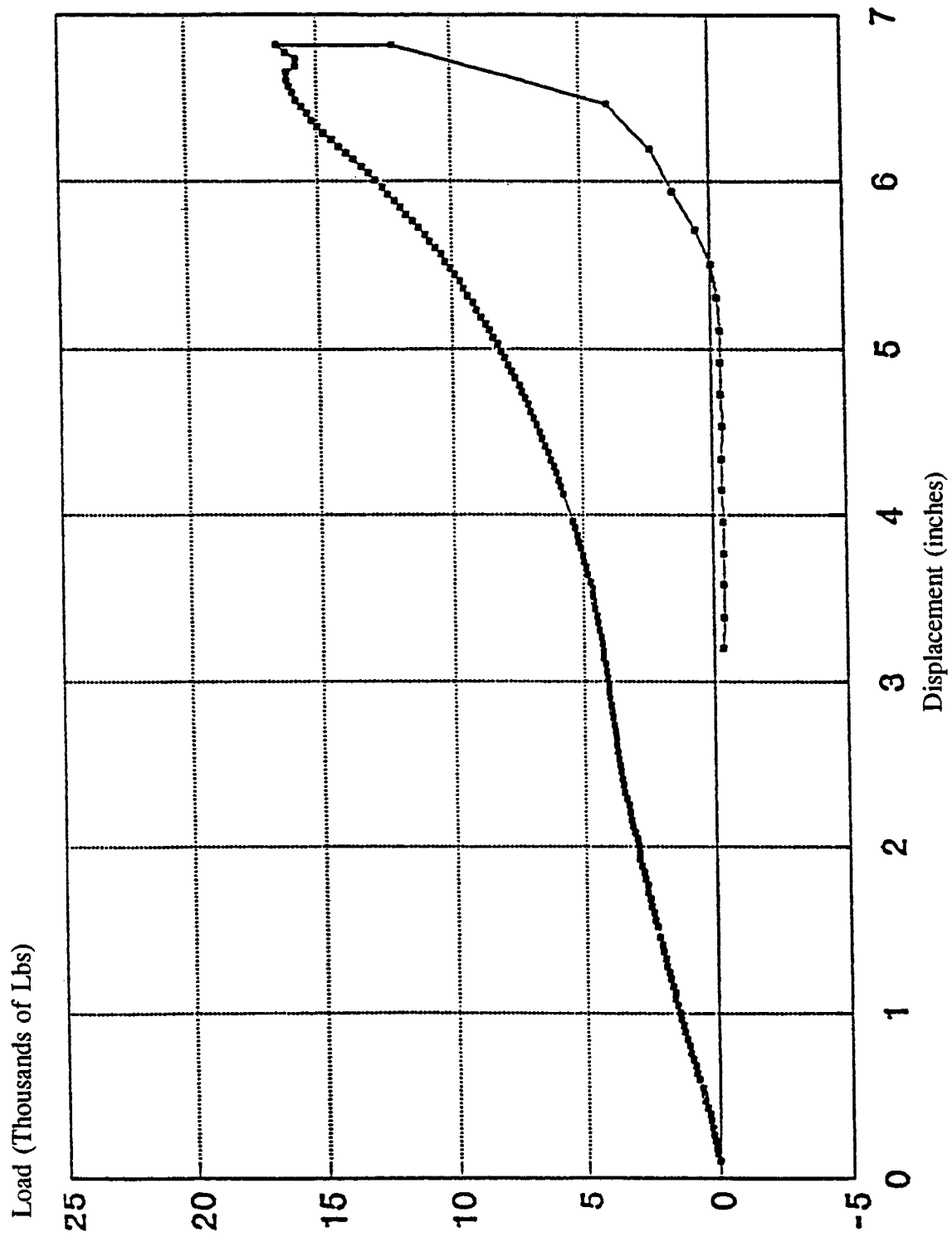
Figure 1: Tensile Load-Deflection Curve of Wood Chip Bale B1



**Figure 2: Tensile Load-Deflection Curve of Wood Chip Bale B2**



**Figure 3: Compressive Load-Deflection Curve of Wood Chip Bale B2**



**Figure 4: Compressive Load-Deflection Curve of Straw Bale B3**

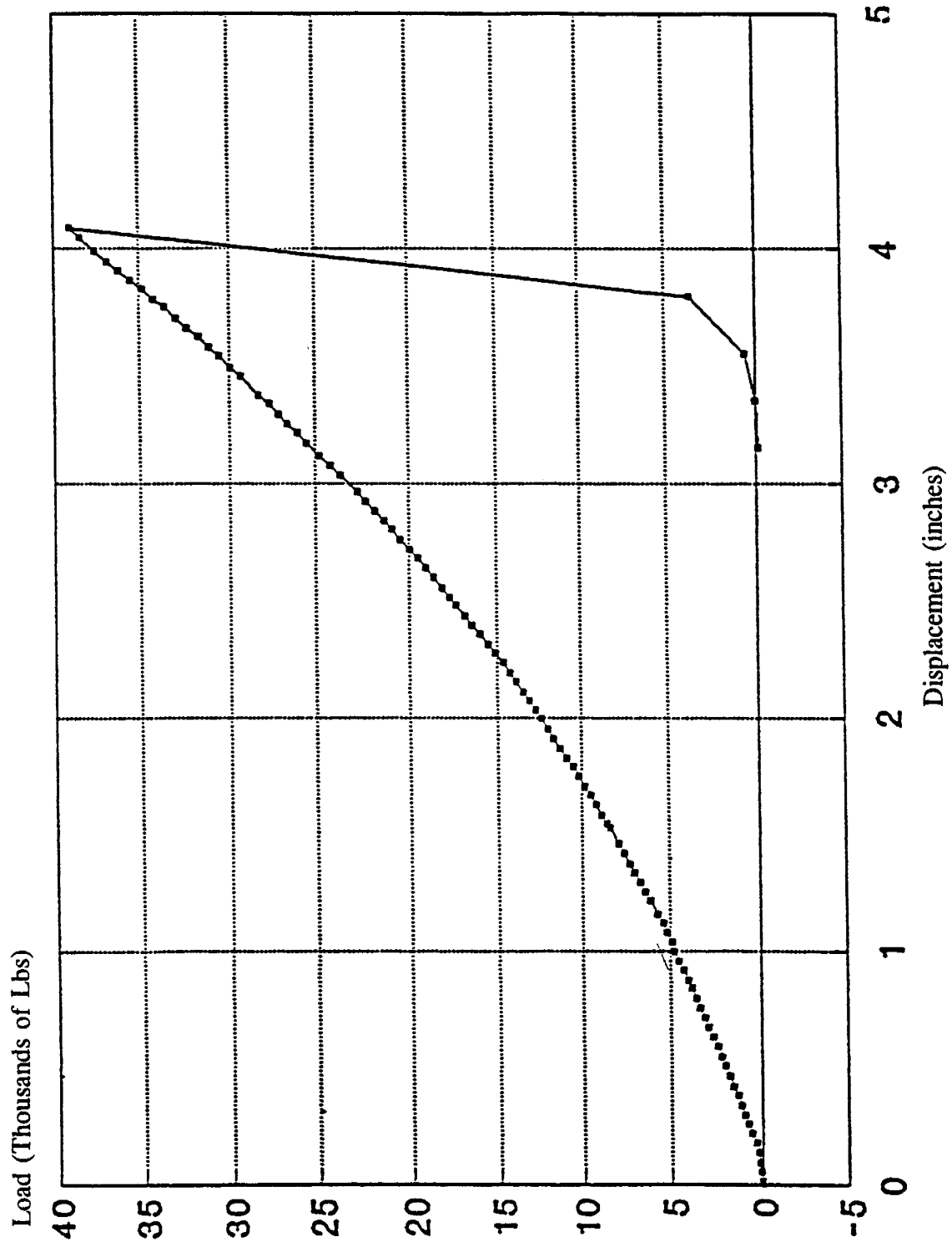


Figure 5: Compressive Load-Deflection Curve of Wood Chip Bale B4

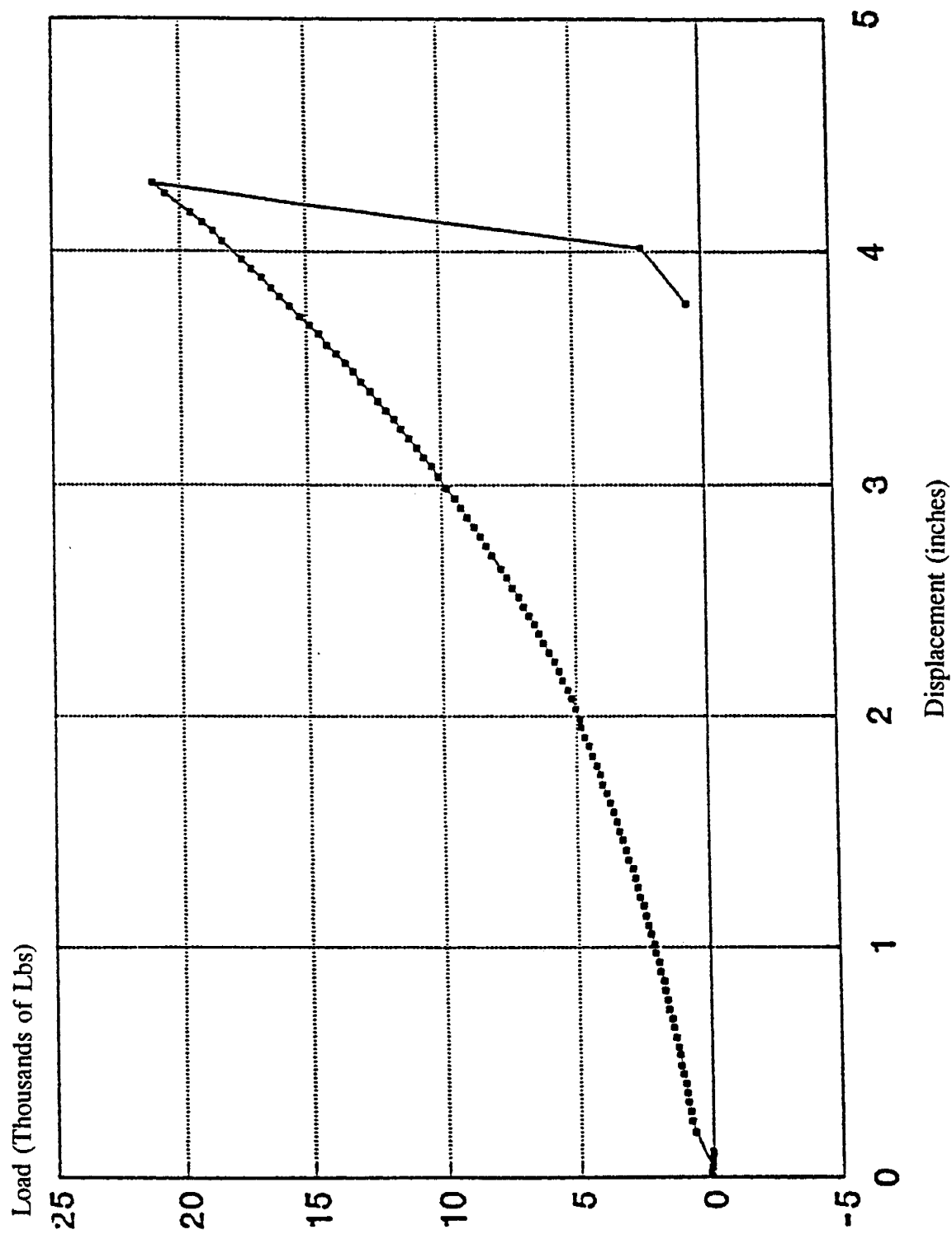


Figure 6: Compressive Load-Deflection Curve of Wood Chip Bale B5

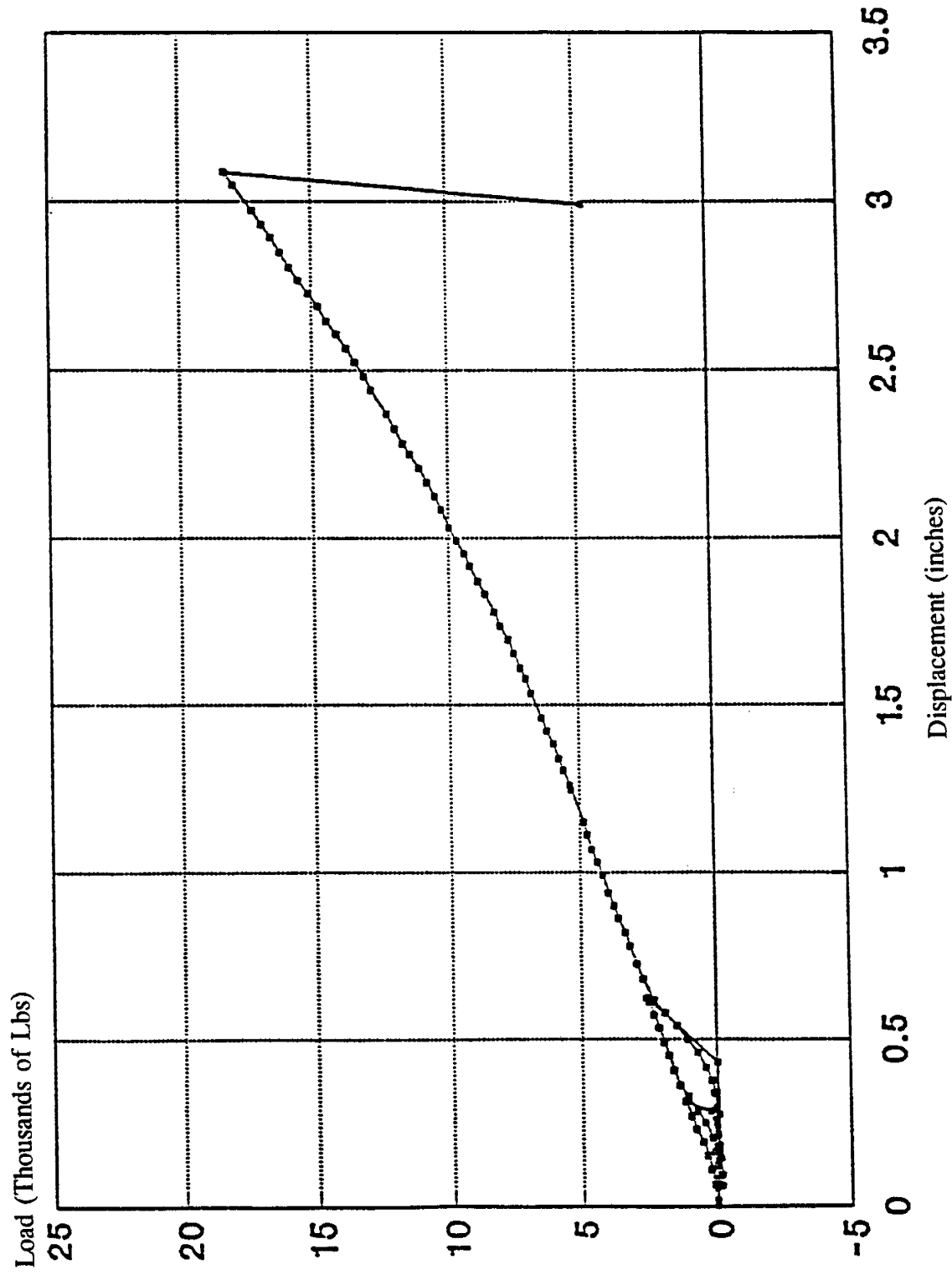


Figure 7: Compressive Load-Deflection Curve of Wood Chip Bale B6

# Load / Deflection Curves — Stuccoed Bioblock Wall Sections

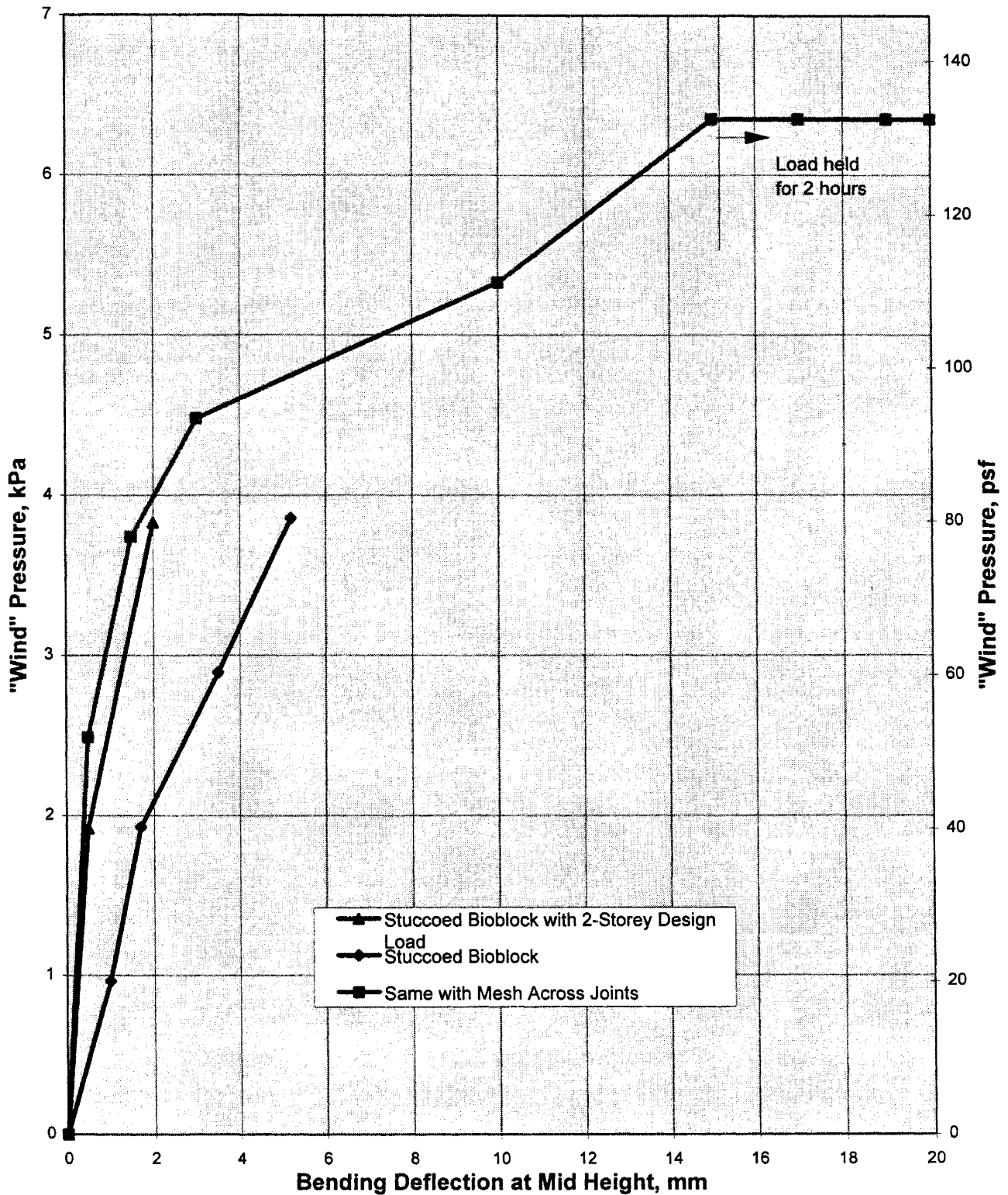


Figure 8



Photo No. 1



Photo No. 2

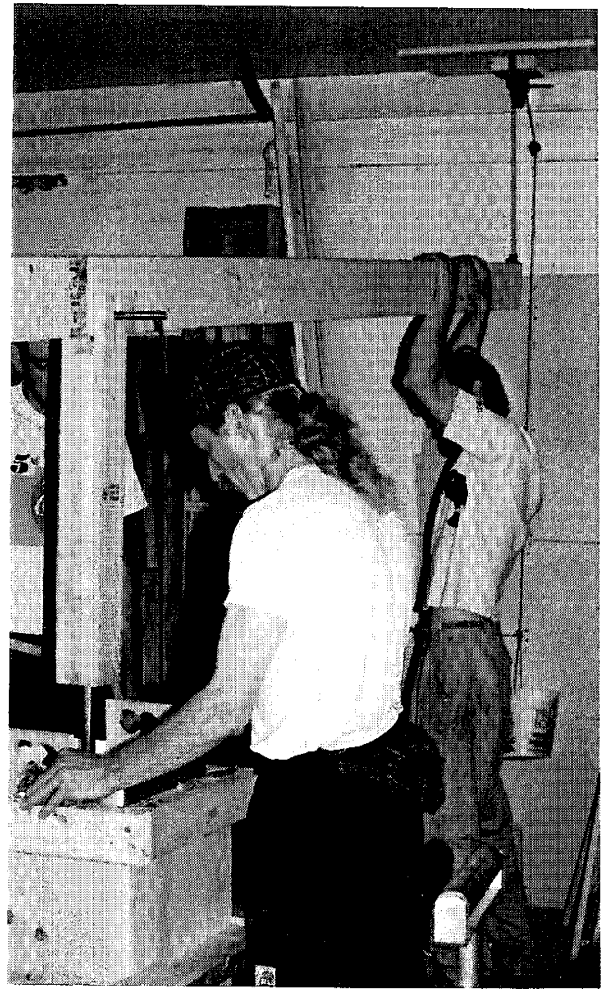


Photo No. 3

Photo No. 6

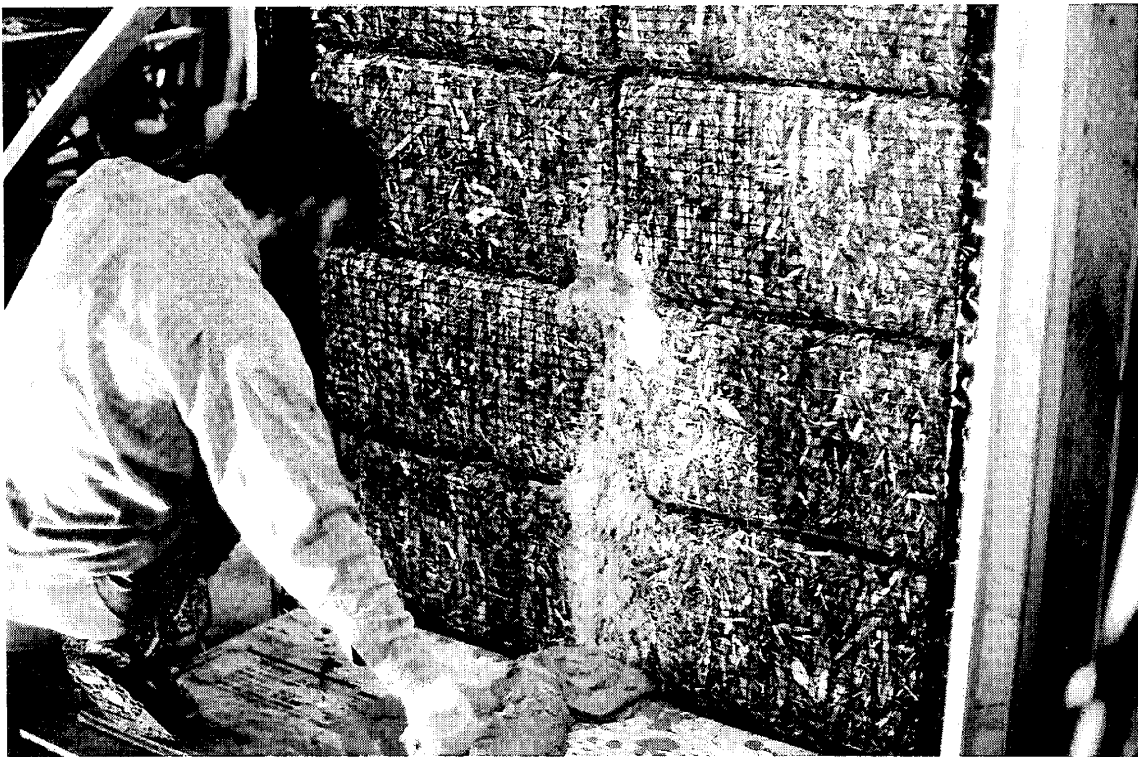


Photo No. 7

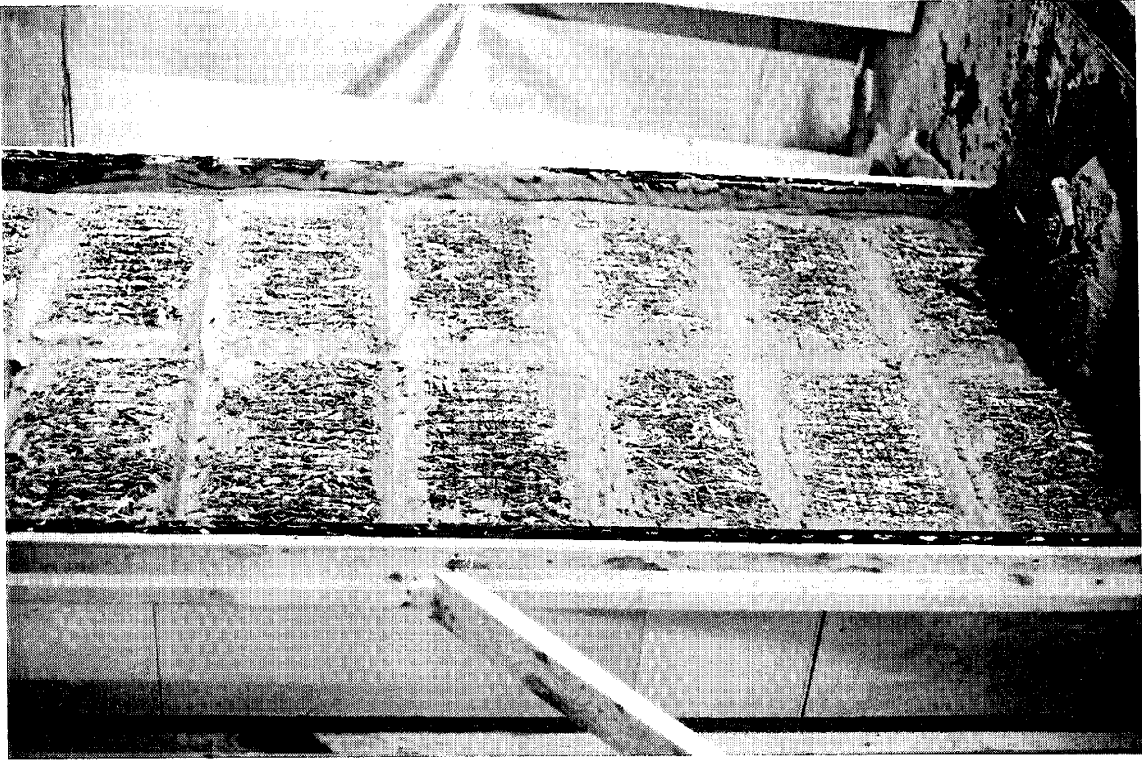


Photo No. 8

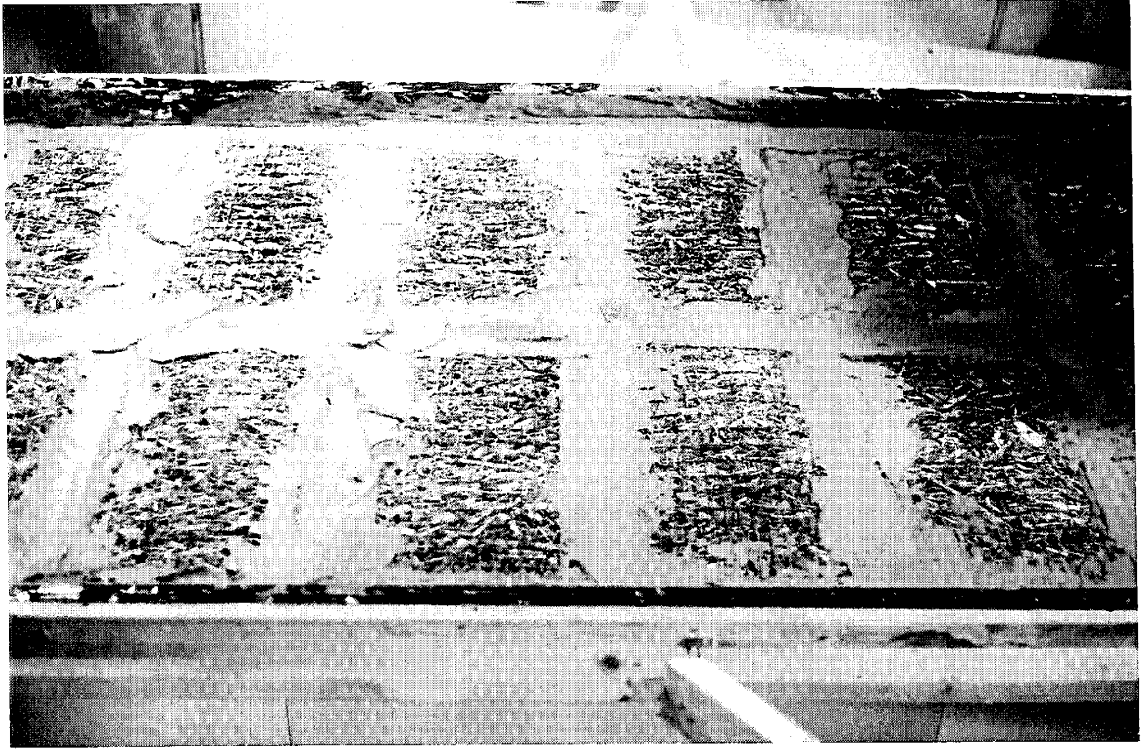


Photo No. 9

Photo No. 10

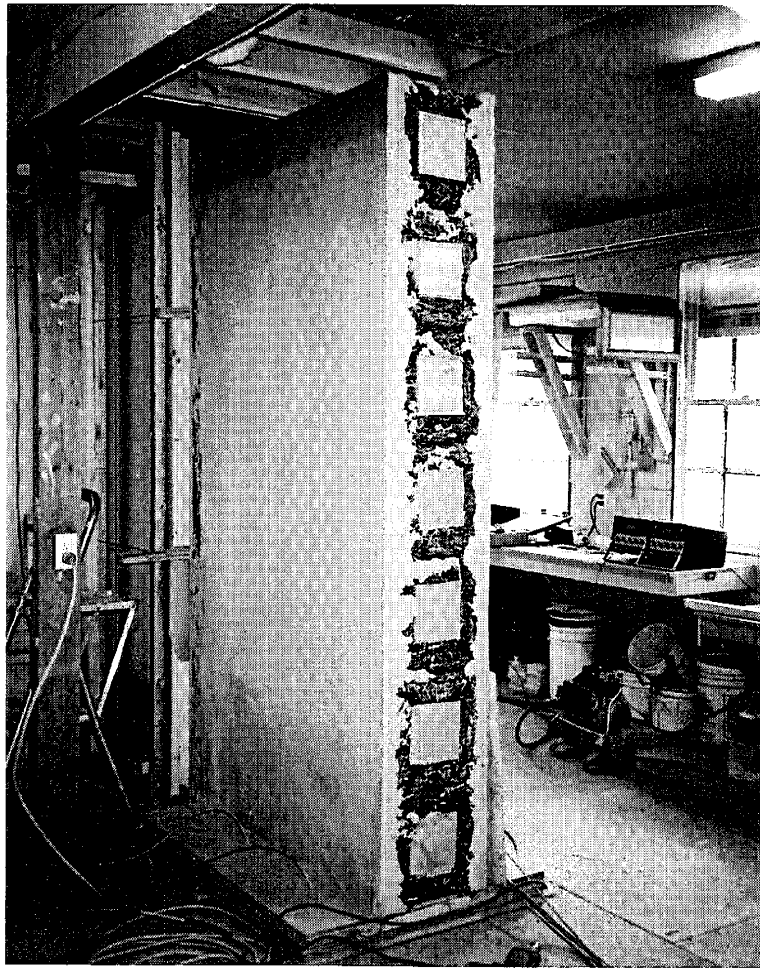


Photo No. 11



Photo No. 12



Photo No. 13

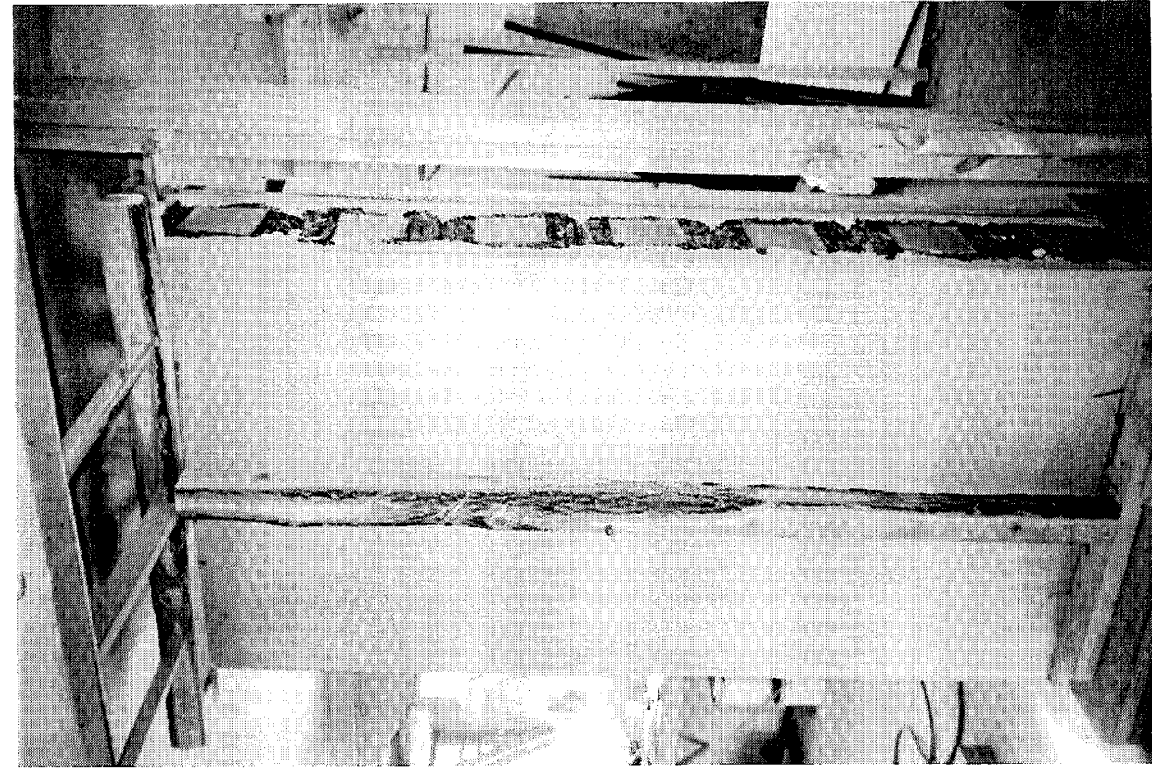


Photo No. 14

*Biocrete Proof-of-Concept Testing*

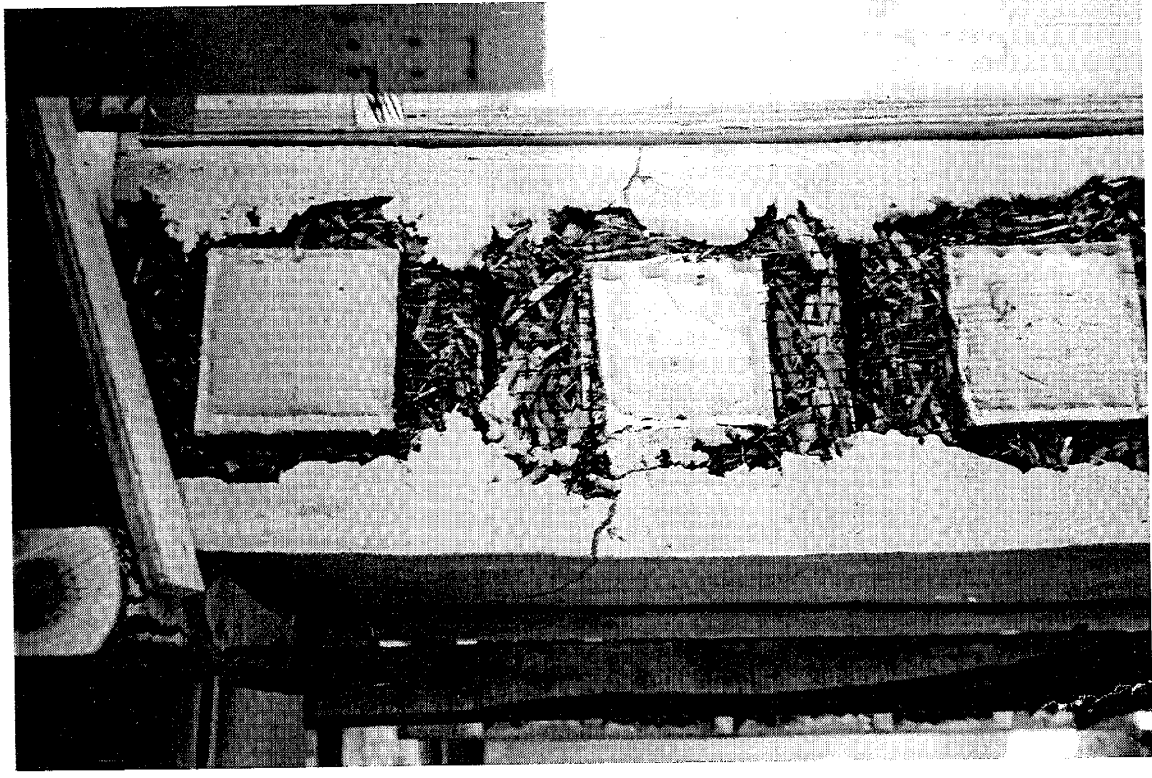


Photo No. 15