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SUMMARY

This paper will illustrate the concept of reinforced concrete structures by the use of computer simulation and an inexpensive hands-on design experiment. The students in our Construction Management program use disposable plastics as a reinforcement to demonstrate their understanding of reinforced concrete and prestressed concrete beams. The plastics used for such an experiment vary from plastic bottles to steel reinforced auto tires. This experiment will show the extent to which plastic reinforcement increases the strength of a concrete beam. The procedure of using such throw-away plastics in an experiment to explain the interaction between the reinforcement material and concrete, and a comparison of the test results for using different types of waste plastics will also be presented in this paper.

A computer analysis to simulate the structural response is used to compare the test results and to understand the analytical background of reinforced concrete design. This interaction of using computers to analyze structures and to relate the output results with real experimentation is found to be a very useful method for teaching a math-based analytical subject to our non-engineering students.

OBJECTIVES

This project was assigned to the students to achieve the following objectives:

i) To develop a basic concept in designing, preparing, and testing concrete structures

ii) to understand the role of reinforcement in reinforced concrete structures

iii) to relate computer simulation with the actual structural response to applied loads

iv) to experience prestress concrete technology

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v) to familiarize students with a systematic step by step procedure for executing and completing research

vi) to involve students with a growing national concern for disposing plastic wastes by the use of an innovative recycling method.

INTRODUCTION

The Building System Design class is a three semester hour comprehensive structural design and analysis course. This course is designed to illustrate the concepts of structures and their fundamentals by using computer analyses and physical demonstrations of model structures. The students in this class apply their understanding of structural analysis in designing, building, and testing model structures in practical experiments. In this class practical design problems are included to develop a general concept for different structural systems. The first two-thirds of the semester is devoted to explaining the force-response relationships of structures. A broad spectrum of structures and their interactions with loads are explained. A structural analysis computer program is used to analyze structural systems. At the end of this period the students are required to form groups to study a particular type of structure. Each of the groups works under the supervision of the instructor and presents its findings in an open forum. This study discusses a concrete project and presents its findings.

Concrete is a very widely used construction material. As a material, concrete is stronger in compression and much weaker in tension. A material course in this respect can teach students about the general behavior of concrete and the practical aspects of its applications. A reinforced concrete design and analysis class could generally teach the importance of the reinforcement in a concrete structure and how many rebars are required to provide the additional tensile strength in the concrete. Apart from these courses a concrete laboratory session would substantially enhance the basic understanding of concrete and its characteristics. For construction majors, however, a laboratory session is more important. In our Building System Design class we have introduced a concrete project to understand concrete as a material and the practical aspects of its placement, testing, and preparation.

This paper will demonstrate the extent to which disposable plastic reinforcement interacts with concrete and increases the tensile strength of concrete beams. Computer analysis is performed to analyze the structure and relate the results with actual structural response to applied loads. The use of such an inexpensive and abundant resource also acquaints students with a national growing concern for managing plastic wastes.

The project was also designed to outline a systematic methodology to conduct and involve students in a research program. The final student project reports describing the limitations and recommendations for future study are also discussed.

PROCEDURE

The Building System Design class was divided into groups, consisting of two to four students each, to work on different projects. Each group was responsible for planning, managing, and executing the project in a systematic manner in order to complete the project on time and achieve its objective. As a guideline to help plan their project they were asked to follow the six step schedule. These activities included:

i) selection of group members

ii) consulting previous projects and literature survey to find any related works

iii) submission of a proposal - basic preparation to complete the project - determining the objectives, highlighting the actions to be performed

iv) execution of the project - determining number, size and shape of beams and cylinders to be prepared, preparing forms, concrete casting and slump testing

v) testing and analysis of concrete specimens

vi) summarizing the work done

The students were also given the following information.

A review of concrete structures and how they behave under the application of loads was provided by solving simple example problems. At this point the student had a basic understanding of flexural stress which results due to a bending moment induced by an applied load. The role of reinforcement was described by studying the computer analysis of an example problem. In this problem the flexural stresses due to an applied load on a simply supported non-reinforced concrete beam were computed for a symmetric cross-sectional beam. The computed stresses due to an increment of load at regular intervals were monitored and compared with the flexural tensile strength of concrete. An attainment of the load carrying capacity of the beam was determined when the computed stress was found equal to the tensile flexural strength of concrete. Although the beam at this stage had reached its full tensile strength the compressive portion of the beam did not. For an effective use of material the additional compressive strength must be counterbalanced by tensile reinforcement. The amount of tensile reinforcement required to resist the balance of the tensile load was also computed. This provided the students with a background on the necessity of reinforcement in concrete beams.

The students were informed to keep track of the schedule and to update it regularly. The project schedule for each group, reflecting their progress, was evaluated by the instructor and timely adjustment was made.

Students were also informed about the ASTM (American Society of Testing Materials) testing specifications for concrete and the importance of following a specified standard in order to achieve a valid test result which can be verified if required. The importance of water in concrete and how it affects the strength of concrete was also pointed out. The absorption and surface moisture of aggregates were not determined but the importance of their consideration in the design of concrete was mentioned. An additional amount of water on the surface of aggregates will increase the net water content of the concrete and eventually decrease the strength of concrete. In this regard the importance of calculating the surface water in aggregates was described in order to determine the correct batch weights.

Finally, they were provided with information about preparing a report. They were asked to arrange the report in five subheadings, namely;

i) Objectives - why they were doing the project

ii) Introduction - any prerequisites, basic information

iii) Methodology - how they would achieve the objective (s)

iv) Results and Finding - what they have found from the test results, interpretation of the results

v) Conclusions and Recommendations - outcome, any suggestions for future improvement of the study

Basic preparation

According to the proposed preliminary objectives of the study the students obtained the necessary materials and prepared the testing devices as required. This took a bit of planning and designing on their part. A few of these project plans to achieve certain objectives are presented below.

a) To illustrate the concept of using tensile reinforcements in concrete beams, disposable plastic molds used for casting test cylinders were shredded and the strips were used in concrete beams as a possible reinforcement. The students had to cut strips of plastic of different sizes and shapes. Different sizes, types (such as perforated ones with different size holes, or with jagged edges) and shapes (with broadened ends) of strips were used in the beams to illustrate the concept of bonding interaction between the concrete and the plastic strips.

Depending upon the objective(s) the students compared the results between the plastic reinforced concrete versus non-reinforced concrete, and also compared concrete with different size plastic reinforcements. The students also used plastic strips with jagged ends which interlock better with the concrete than plain plastic strips.

b) to understand the performance of different types of plastics they used plastic soda bottles and auto tire strips as reinforcing materials. To increase the bonding resistance of the plastic, the soda bottle strips were punctured. Fiberglass mesh was also used to see its impact in increasing the strength of concrete and in minimizing the weight of the composite beam. Layers of punctured polyfibers mat were also used to differentiate the effect of the location of reinforcement in a reinforced concrete beam.

c) to determine the effect of the distribution of reinforcement, plastic strips were also placed randomly in some structures and uniformly in others. Here the uniform distribution was attained by maintaining equal number of strips at any cross section of the beam. The proportions of plastics in the concrete molds were monitored by counting the number of strips in each specimen. To optimize the use of plastic strips in a simply supported beam, plastic strips were distributed non-uniformly along the length of the beam. In this case the optimization referred to the maximization of load capacity for the same amount of reinforcement. A higher percentage of plastic reinforcement was used at the mid-span than at the rest of the body to strengthen the weaker part of the beam.

d) to experience the prestressing concept and its behavior in concrete beams, an auto tire strip was used as a prestressing tendon. A custom built three-sided wooden box with two holes on the shorter side walls was used to mold the prestressed beam. The tire strip was slipped through the holes of the box. One end of the strip was fastened to the supporting board by drilled bolts. The other end of the strip was connected to a fixed block (support) by a hook. The adjustable hook was fastened to the block by a nut and washer on one side and the tire strip connection on the other side. The tire was then stressed by tightening the hook with a wrench. The prestressed tire strip inside the beam was cut jagged approximately three and half inches on both ends. Figure 1 shows the prestressing mechanism used for this case. An identical regular (non-prestressed) tire reinforced beam was also prepared to compare the results between prestressed vs. non-prestressed cases.

In all cases non-reinforced identical concrete beams were prepared to compare the reinforcing property of the plastic-concrete structures as opposed to the homogeneous concrete beams. The students had to figure out how many beams were to be prepared to carry out the experiment. For each of the comparisons a minimum of two specimens was used. Three test cylinders were prepared for each batch of concrete.

The students first had to prepare the forms into which they would pour the concrete mixture. Mostly they made rectangular beams varying in dimensions from group to group. One group made 9 beams of dimension 3.5"x3.5"x12", while another group made beams of 3.5"x6"x22". A 2.5"x5"x16" beam was used for the prestressed concrete beam project. The students learned to put motor oil in the flat areas and Vaseline in the joints to prevent the concrete from adhering.

Once the number of beams and test cylinders was known they computed the required volume of the concrete to be prepared. A known proportion by weight for the ingredients, such as 1:2:4 (1 part of cement, 2 parts of sand and 4 parts of gravel) was used to compute the required amount of cement, water, sand and gravel. A known water cement ratio, e.g., 0.45, was also prescribed to determine the amount of water.

The computation of the amount of ingredients, however, required a knowledge of the material's volumetric properties such as unit weight, percent of voids, and percent of water absorption. In absence of actual material properties students had to perform the volumetric testing for sand, cement and gravel. A rough estimation of unit weight was determined by measuring the weight of the material in a cylinder divided by its volume. An example of such testing is presented below:

Weight of sand in a (4"x8") cylinder excluding the cylinder's weight = 5.419 lbs
Volume of the cylinder = (area x length) =0.05818 ft^3
Unit weight of cement = 5.419/0.5818 = 93.15 lbs/ft^3

Plastic strips and Quality tests

The plastic strips used in the bottom part of the beam were tested for determining their tensile strength. Three specimens of each of the different types of plastic strips were tested in a tensile testing machine. The average tensile strength for the plastic mold strips (polyethylene) was found to be 1,894 psi. For the plastic bottle strips the average tensile strength was limited to the percent of elongation of the plastic. In this case the plastic had elongated about two times its length before it broke and the average tensile strength was about 2,500 psi. The percent elongation is important since inside a concrete structure, plastic can not attain its full strength or rather can not elongate to its full extent due to limitation in the elongation of the composite structure (plastic inside the concrete). The contributing strength of plastic in a concrete element is controlled therefore by the concrete's elongation capacity. The plastic strength is limited to an equivalent strain equal to the cracking strain of concrete (about 0.003 for regular concrete).

The tensile strength for the auto tire strand was 52,112 psi. This strength was determined for the composite steel-mesh reinforced plastic (auto tire) using the tensile strength testing machine. The load at which the steel wire tended to slip out of the plastic was considered as the capacity of the tire strip. During prestressing the tire strand was stressed below such a limit to avoid any form of slippage.

Concrete Casting and Curing

Using the concrete mixing machine the concrete was prepared and the mixture poured into the molds. All beams and test cylinders were poured using standard concrete practices and procedures. For each batch a concrete slump test was performed to measure the consistency of the concrete. Slump tests were performed according to the standard ASTM C143 practice. The students were able to see how the curing proceeded.

The beams and cylinders were allowed to cure (in air during the entire time) prior to testing. The students knew that allowing the concrete to cure for too long would increase its strength to the point where the strength of the plastic used would become lower relative to that of the concrete. This would mean that the plastic would be useless in reinforcing the structure, as only a material with a strength greater than the tensile strength of concrete can add any significant reinforcement. The students allowed a week's time for the curing to be complete. The students had to make their own assessments as to the readiness of the concrete structures.

Concrete Testing and Analysis

Concrete cylinders were tested in the compression testing machine to measure their compressive strength. The concrete beams, with and without plastic strips of different sizes and shapes, were tested for their flexural tension strengths. In order to test the beams using the compression testing machine, students had to build a specifically designed beam breaking platform. One such platform, as shown in Figure 2, allowed for a concentric load from the hydraulic machine to be applied at the mid span of a simply supported beam. The breaking loads for the beams were determined for each of the test objects. This load was used to compute the flexural strength in tension by using equation (1).

$$F_{bt} = \frac{M}{S_x} \quad psi \qquad \cdots\cdots(1)$$

where,

$$M = \frac{Pl}{4} \quad lbs-in \qquad ,and \quad S_x = \frac{bd^2}{6} \quad in^3$$

In equation (1), M is the moment in lbs-in due to a mid span load, P, applied to a beam of span, l . S_x is the section modulus for a rectangular beam (bxd). F_{bt} is the tensile-flexural stress in the extreme bottom fiber of the beam.

FRAMEMAC, a structural analysis program was also used to analyze the beam. The necessity of using a computer program was more obvious when analyzing a complicated structure such as multi-story building frame, and non-traditional loads. A two story frame structure due to applied loads, for example, can be analyzed by using the computer program with a lesser amount of effort than by using the conventional procedure. The applied stresses for each member in such a structure can be computed. A successful application of such computer analysis in teaching the fundamental concepts of structural systems was demonstrated by the author in a previous paper (Ref #1). The author has furthered his efforts by using an advanced computer analysis in analyzing the plastic reinforced beams.

It was clear to the students that the plastic reinforced beam was not a solid homogeneous material like a solid steel beam. In making the beams for the project, the plastic was randomly distributed at the bottom - more concentration at the mid-span than the two ends of the beam. This was done to strengthen the most critical part of the beam i.e., the mid-span, which attains maximum flexural stress. This means the beam will have more strength (to an extent more stiffness) at the mid span than at the ends. Also for concrete beams, material properties at the top of the neutral axis differ from the bottom half. By realizing the non-homogeneous distribution of materials and plastic reinforcement, it was understood that the simple FRAMEMAC analysis, which considers a single property for each beam element, cannot accurately analyze such a beam. At this point the Finite Element (FE) analysis was introduced with very little mentioning of its analytical background. An FE is important for this analysis since by dividing the beam into a number of blocks with different material properties in each block the actual material non-homogeneity can be accounted for. A group of students was assigned to perform the finite element analysis for the plastic reinforced beams. The results and the procedure for this project will be discussed in a different paper.

An analysis of the prestressed concrete beam was also performed to determine the additional strength provided by the prestressed tendon. The mid-span load which caused the beams to fail was used to compute the flexural stresses for both cases. The flexural stress due to the applied load for both reinforced and prestressed beams was compared to determine such a difference. The difference in the flexural stresses between these cases is the additional strength which is developed due to the prestressed mechanism.

RESULTS

The flexural strength comparison results for four groups are presented in Tables 1 to 4. 1"x6" size plastic soda bottle strips were used by group one as a reinforcement material.

Shredded plastic strips (of concrete test-cylinder molds) of different sizes were used by groups two and three. The length for the beams, L, and their cross-sectional dimensions, b for width and d for depth, are also presented in these tables. These tables also present the slump value and compressive strength for each batch of concrete.

The test results show that although the strength differences are marginal, the plastic appears to aid in increasing the tensile strength upon reinforcement. The test shows that the beams that did not contain plastic were brittle and fractured completely at breaking load. However, those containing plastic strips maintained their original cast state at breaking load without a complete collapse. Figures 3 and 4 show such a nature of failure in the test beams. In table one it is shown that the uniform placement of plastic with holes of about 1.8" diameter does not increase the beam's strength over the results of a non perforated plastic reinforced beam. This is because the holes in this case were not effective in interlocking with the concrete particles to enhance the bonding with the aggregates.

Table two shows that uniformly reinforced beams withstand an average of 8.1% greater tensile stress than the beams with no reinforcing. The cylinders, on the other hand, with uniform reinforcing broke with approximately 11.7% less stress than the cylinders with no reinforcing. In this case, it was also found that the plastic strips left a clean smooth impression on the surface of the broken cylinders when removed, showing that the strips did not have proper bonding with the concrete.

Table three shows that most significant increase in the strength occurred in using the plastics with jagged edges, about 2.5 times more than the plain beam. It was found that the jagged edged plastic broke while the plain edged plastic slipped out from the concrete when the broken beams were bent to remove the plastic from the concrete beam. This test showed that the rough edges of plastic provided extra gripping to aid in bonding with the concrete. Also, the smaller size plastic (1/8") provided greater strength than the larger size plastic reinforcing (1/4").

Table four shows a substantial increase in the strength of prestressed beam over regular reinforced concrete beam. The prestressing of the beam increased the beam's strength by six times. The load shown in this table is the mid-span load which caused the beams to fail.

Table 1: Test result for concrete beams, with and without (shredded soda bottles) reinforcement

Group #	Slump, in	Average Compressive Strength, f'_c, psi	Average 8 days Flexural Tensile Strength, f'_t, psi (b= 3.5", d=6", L= 22")		
			Plain (no plastic)	Uniform Holes* *(1/8" Dia.)	Uniform no Holes
1	2.5	3,103	583	594	594

Table 2: Test result for concrete beams with and without (shredded plastic cylinder mold) reinforcement

Group #	Slump, in	Average Compressive Strength, f'_c, psi		Average 8 days Flexural Tensile Strength, f'_t, psi (b= 3.5", d=3.5", L=12") (plastic size, 8" long, 3/32"x1/4" cross section)	
		Plain	with Plastic	Plain	Uniform plastic
2	4.5	2,150	1,899	635	687

Table 3: Test result for concrete beams with and without (shredded plastic cylinder mold) reinforcement

Group #	Slump, in	Average 8 days Compressive Strength, f'_c, psi		Average 8 days Flexural Tensile Strength, f'_t, psi (b= 2", d=4", L=24")			
		1/8" strips	1/4" strips	plain	1/8" Plastic	1/8" plastic, jagged edges	1/4" plastic
3	4.5	1,460	2,070	103	271	361	258

Table 4: Test result for prestressed vs. regular reinforced concrete beams (Both beams were reinforced with a 0.4 square inch auto-tire strip)

Group #	Slump, in	Average 14 day Compressive Strength, f'_c, psi	Average mid-span load capacity, P, in pounds (b= 2.5", d=5", L= 16")		
			Plain (no plastic)	Reinforced Beam	Prestressed Beam
4	1.5	2,467	250	1,030	6,150

CONCLUSIONS

The oral presentations and written reports from the students showed their enthusiastic involvement in the cost effective hands-on design experiment. The project was very helpful for the students in understanding the practical aspects of reinforced concrete beams. It required each student to participate in designing concrete, testing beams, and summarizing the test results in a systematic way.

The project clearly showed the importance of reinforcement in a concrete beam to increase its flexural tensile strength. The test results also differentiated between the brittle and ductile nature of structural failure. Beams with no plastic failed abruptly and severed completely while the beams with plastic did not. The test results of concrete beams reinforced with plastic strips, with and without jagged edges, showed the importance of the bond-length of rebars in achieving the strength of concrete beams. This conclusion is made by an observation of the greater bonding strength of jagged edged plastic reinforced beams than the plain surface plastic reinforced beams. The "honeycomb" structure found in some of the concrete beams showed the necessity of vibrating the concrete while pouring into a mold. A substantial increase in strength due to prestressing shows the importance of prestressed beams over regular reinforced concrete beams.

The recommendation part of the student's reports shows their interest in the project. A few of the recommendations include a) using much greater grade of plastic - like disposed auto tire to achieve the desired results, b) perforating the plastic with bigger holes (depending upon the maximum aggregate size) for increasing the bonding between concrete and the reinforcement, and c) using long strips extending the whole length of the beam.

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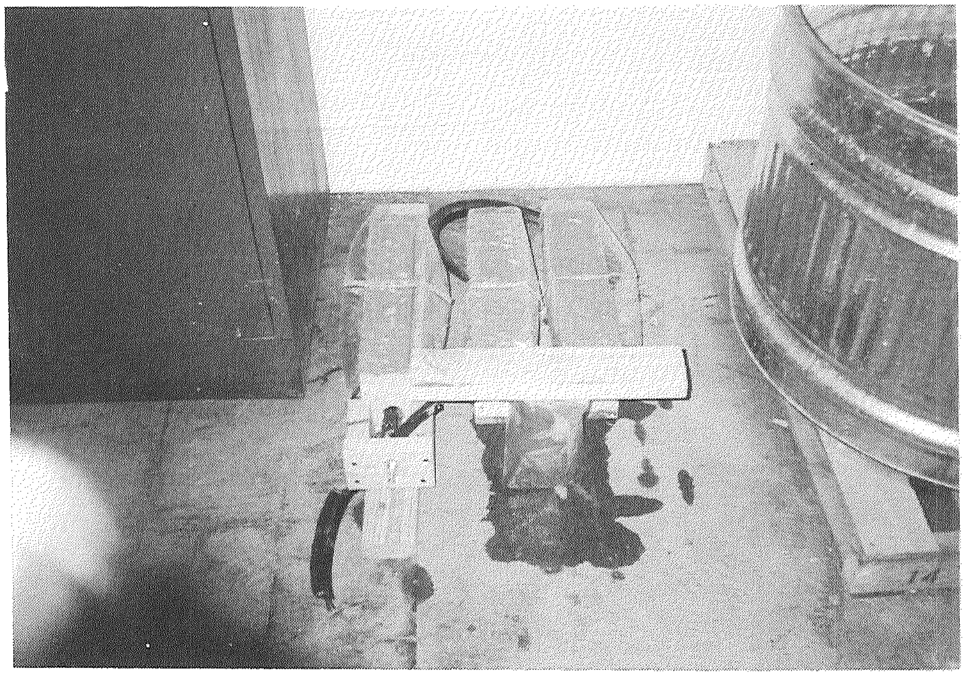

Figure 1: A Prestressing Mechanism.

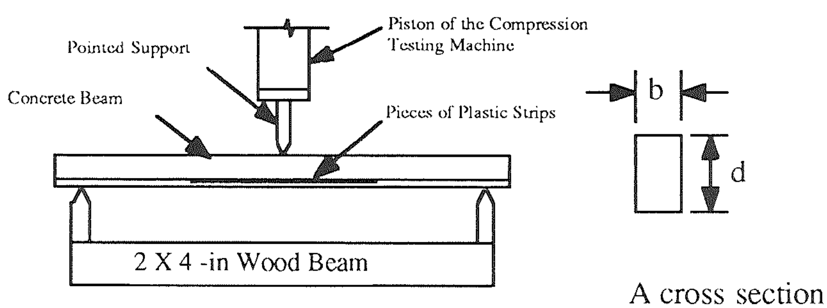

Figure 2: A customized Beam Breaking Platform

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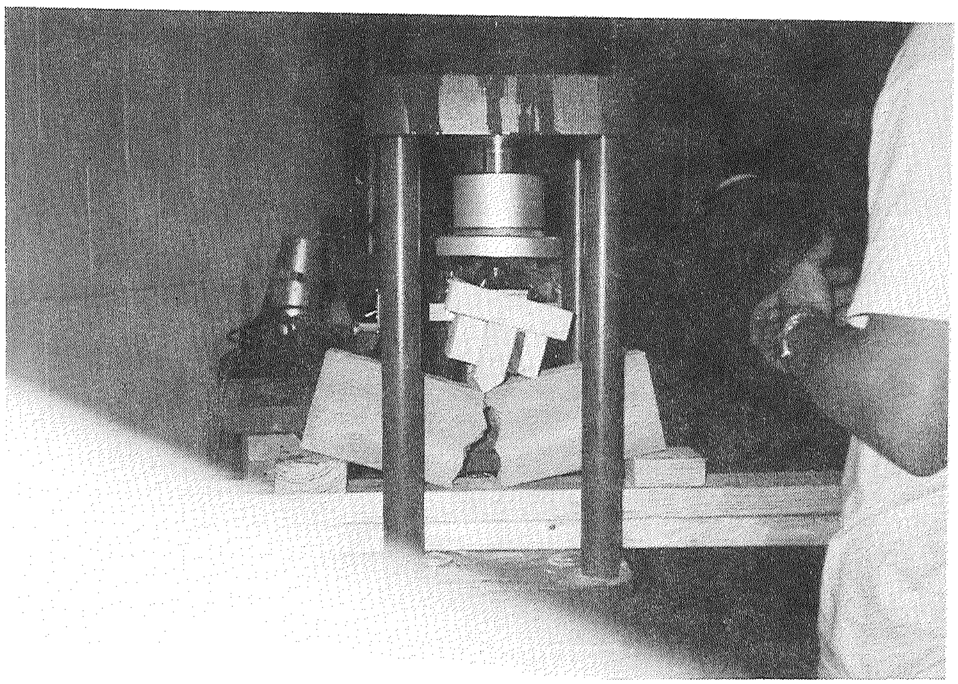

Figure 3: A Brittle type Failure in a Non-Reinforced Concrete Beam.

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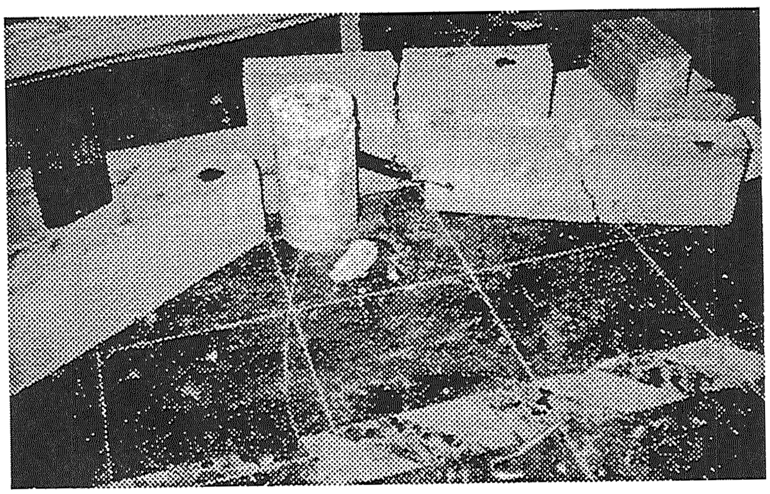

Figure 4: An Auto-Tire Reinforced Concrete Beam Failure.