C-BEAM
ENVIRONMENTAL
ROOF

C-BEAM ENVIRONMENTAL ROOF

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NOTATION

A_c	=	Area of concrete
A_{cp}	=	Area of the precast component
A_s	=	area of tensile reinforcement/prestressing steel
A'_s	=	Area of compressive reinforcent
A_{sv}	=	Area of the two legs of a shear link
b	=	Width of section
b_c	=	Breadth of compression face
b_t	=	Width of equivalent tension zone area
b_v	=	Average width of rib of a T-beam, L-beam or C-beam
b_w	=	Width of section in tension zone/width of equivalent tension zone area
C	=	Total compressive force in concrete at ultimate state
d	=	Effective depth to tensile reinforcement
d_r	=	Depth to which the compressive stress block extends into the rib of a T, C or L-beam (below the top flange)
d_x	=	Depth to the centroid of the compressive stress block
e	=	eccentricity of prestressing tendons below section centroid
E_c	=	Short-term modulus of elasticity of concrete at 28 days
E_{ci}	=	Short-term modulus of elasticity of concrete at transfer
E_{cp}	=	Short-term modulus of elasticity of the precast component
E_{cs}	=	Short-term modulus of elasticity of the concrete topping
E_{ct}	=	Short-term modulus of elasticity of concrete at an age, t
E_{eff}	=	Effective long-term modulus of elasticity of concrete over a given period
E_s	=	Modulus of elasticity of reinforcing/prestressing steel
f_b	=	Stress at bottom of slab under service load
f_{bi}	=	Stress at bottom of slab at transfer
f_{ci}	=	Concrete strength at transfer
f_{cp}	=	Design compressive stress at centroidal axis, at end of transmission length, due to prestress, after all losses

f_{cpx}	=	Design compressive stress at centroidal axis due to prestress at distance x from end of slab, within the transmission length
f_{ct}	=	Allowable tensile stress in concrete
f_{cu}	=	Characteristic strength of concrete at 28 days (or later)
f_{cut}	=	Characteristic strength of concrete at an age, t
f_k	=	Characteristic compressive strength of masonry
f_{cp}	=	Maximum extreme fibre compressive stress due to prestress after all losses
f_{pc}	=	Design effective prestress in tendons after all losses
f_{pt}	=	Maximum extreme fibre stress due to prestress after all losses
f_{pu}	=	Characteristic strength of prestressing steel
f_s	=	Service stress in tension reinforcement
f_{sp}	=	Axial stress in the precast component due to differential shrinkage
f_{ss}	=	Axial stress in the concrete topping due to differential shrinkage
f_t	=	Design principal tensile strength of concrete/stress at top of slab under service load
f_{ti}	=	Stress at top of slab at transfer
f_y	=	Characteristic strength of reinforcing steel
f_{yv}	=	Characteristic strength of shear reinforcement
F_{cp}	=	Compressive force in the precast component due to differential shrinkage
F_i	=	Initial jacking force
G_n	=	Nominal dead (self-weight) load
h	=	Thickness of slab
h_r	=	Depth of precast component
I_c	=	Second moment of area of concrete section
I_{cp}	=	Second moment of area of the precast component
K_t	=	Coefficient used in calculation l obtained from 5.8.4.5 of SABS 0100:Pt.1.
l_t	=	Transmission length of prestressing wires (not less than overall depth of precast element
L	=	Length of the slab/distance between centres of supports
M_o	=	Moment necessary to produce zero stress at the extreme tension fibre, assuming 56% of final prestress force is acting

M_r	=	Moment of resistance at ULS
M_s	=	Design service moment
M_{sw}	=	Moment due to self weight at service limit state
M_u	=	Design ultimate moment
M_{ux}	=	Ultimate moment at position x
N_L	=	Number of wires
P_f	=	Final prestress force after all losses
P_i	=	Initial prestress force after transfer
Q_n	=	Nominal imposed load
S_v	=	Spacing of shear links
T	=	Total tensile force in reinforcing or prestressing steel at ULS
v	=	Design shear stress at ULS
v_c	=	Design shear resistance of concrete
V	=	Design ultimate shear force
V_{co}	=	Ultimate shear resistance of uncracked section
V_{cr}	=	Ultimate shear resistance of cracked section
V_x	=	Ultimate shear at position x
w	=	Uniformly distributed load/crack width
W	=	Point load
x	=	Depth to neutral axis/distance from end of span
y	=	Height to centroid of steel force above soffit
z	=	Lever-arm
Z_b	=	Section modulus at bottom of slab
Z_t	=	Section modulus at top of slab
d	=	Elastic shortening of a concrete element/deflection
`$_{cc}$	=	Specific creep
`$_{cs}$	=	Free shrinkage strain of the slab concrete
c_c	=	Importance load factor
c_f	=	Partial factor of safety for loads
c_i	=	Partial load factor
c_m	=	Partial factor of safety for material strength

$\hat{A}$	=	Creep factor/diameter
r_i	=	Mean stress in concrete at wire centroid after transfer

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SYNOPSIS

South Africa is experiencing great movements of people from rural areas to towns mainly because of the need to find work. Accommodation is limited and expensive, forcing many to live in informal homes. The municipalities, in an attempt to accommodate as much as they can, provide small plots, which basically can only accommodate a house and a very small garden.

This country like other countries of the world has also embarked on numerous low-cost housing schemes to accommodate the homeless. Because of economic realities and because high-rise options are not considered acceptable, the most practical solution has resulted in large-scale low-density urban and suburban housing developments. Low-pitched metal-sheet roofs are provided because they are the most cost-effective. Lack of space within the homes and tiny surround-gardens are major problems to residents seriously limiting lifestyle. Other problems associated with these developments concern environmentally intrusive effects, the need for better security and other social concerns, and stormwater runoff.

This thesis discusses a usable flat urban and suburban roofing for existing and new houses by means of a system known as 'C-beam'. A usable greened concrete flat roof replaces the traditional pitched metal-sheet. The new roof provides sitting space for family members and is used to grow plants in pots. A construction manual is to be developed by which the constructors will build the roofing without the use of cranes and other expensive sophisticated construction machinery. The house owner can construct their own flooring/roofing; that is, the process will provide additional jobs, and hence positively affect economy. The manual includes the means of effective control by municipal authorities to ensure adequate and safe standards.

Greening of the roofs will not only provide the potential for growing food from the plants, but it will also improve the environment of the area, including the reduction of stormwater run-off, by retaining some water in the soil on rooftops.

CHAPTER 1

INTRODUCTION

1.1.1 A World-wide Problem

Environmental issues are a key problem in this century. What are we doing? ... seemingly something is done but what is being done is not fast enough to counteract the present and future effects of these environmental disasters.

According to many sources one urgent matter that needs addressing immediately is the depleting ozone layer as evidenced by early warning signs such as El Nino and global warming (Frescura, 1991). These are both related in changing the entire earth's climatic conditions causing regular flooding and then extreme droughts in different parts of the world. The areas of the world known as the "food baskets," because of the large amounts of agricultural production, are now experiencing severe crop failures due to these climatic changes. These crop failures putting a strain on the precious resources that help to feed many nations.

With global warming and an ever-increasing population, these problems can be expected to continue at the same alarming rate. Unless something is done to help slow the process down it must be concluded that the earth is heading for a disaster.

In the first-world countries, the resources consumed are double the amount *per capita* than that of an undeveloped or "third- world countries."(Lawrance,1997). If all third- world countries could develop to first-world standards and at the same time consume the same amount of resources that the first-world counties consume, then the world's resources will become exhausted. In addition, it is possible that the increase in pollution will cause the ozone layer to totally disappear and it will mean the end for all life on this planet.

If we examine all the environmental and social problems in the world today it must be concluded that we have only ourselves to blame for all the problems. Instead of continuing in the same downward trend we have to do something to slow the process down and ambitiously try and reverse some of the damage that we have done to the world.

The first and most obvious step in trying to slow down some of these environmental problems that we have created is to integrate our way of living with the environment.
We can only truly say that we are developing once we have achieved this.

1.1.2 A Local Problem

South Africa is experiencing great movements of people from rural areas to towns mainly because of the need to find work. Accommodation is limited and expensive, forcing many to live in informal homes. The municipality, in an attempt to accommodate as many as they can, provide small plots which basically can only accommodate a house and a very small garden.

This country like other countries of the world, has also embarked on numerous low-cost housing schemes to accommodate the homeless. Because of economic realities and because high-rise options are not considered acceptable, the most practical solution has resulted in large-scale low-density urban and suburban housing developments. Low pitched metal-sheet roofs are provided because they are the most cost-effective. Lack of space within the homes and tiny surround-gardens are major problems to residents seriously limiting lifestyle. Other problems associated with these developments concern environmentally intrusive effects, the need for better security and other social concerns, and stormwater runoff.

One means of addressing the problem, which is the main objective of this research, is to develop useable flat urban and suburban roofing for existing and new houses by means of a system known as 'C-beam'. The pitched-sheet roofing is to be replaced by a useable 'greened' concrete flat roof which can be constructed by the owner.

1.2 OBJECTIVES.

The reasons for this study are to increase the living space that house-owners have in a high- density housing area and make people more self-sufficient and improve the spirit of entrepreneurship, provide ideas for better integrated environmental living and create pride within communities by raising the standard of living. The aim is to convert existing pitched roofs in high-density areas to flat accessible roofs. This will provide an area in which the owner can grow his or her own food and/or other plants, and also create a safe recreational area for the home.

The major difference from the conventional systems is that the community will construct their own flat roofs. Unlike most other housing projects where a major contractor does all the work, this project will be community driven. This is because government and world aid organisations for such programmes are no longer providing the "end product," without effort from the community. Aid for these programmes now require the community to help themselves rather than the government continually giving "hand-outs," that are neither effective nor appreciated by the communities.

Under the present system the contractor would come into the community and complete the work without employing any of the local people. This means that once the project is complete the community would not have gained any skills or developed in any way. They are just provided with homes to which they did not contribute or know how to maintain.

The roof slab will be erected without the use of cranes and no steel fixing should be required.

In these high-density communities the problem is greater and more challenging, both environmentally and socially than in less densely populated communities. This is mainly because of the confined space that the people have to live in and therefore any environmental problems are magnified.

1.3 SCOPE

The scope this thesis covers the following:

(a) Design of C-Beam

This involves upgrading the existing precast prestressed concrete C-Beam design (Chalatse 1998) to cater for plant-pots loading.

(b) Construction of the C-Beam

This includes assembling prestressing beds, assembling formwork, casting and curing C-Beams. Construction of C-Beams in future is intended to be done by a specialist company and beams sold to house owners. The construction now is for the purposes of research.

(c) Testing the C-Beam

Tests on the C-Beam included the following:

(i) C-Beam structural soundness, and the following are the tests done: concrete compressive strength, cracking, handling, deflection, interlocking and waterproofing.

(ii) C-Beam environmental roof construction. This comprises transporting beams to the rooftop, interlocking beams, waterproofing and screeding the floor. The intension for the construction in future is for the municipality concerned to train house-owners on construction, safety and quality control through seminars before construction.

(iii) C-Beam environmental roof concept – this involved gathering feedback from communities about the idea of C-Beam environmental roof.

(d) Construction Manual

Compilation of the C-Beam environmental roof construction manual was made to guide builders on how to construct a proper C-Beam roof.

1.4 METHODOLOGY

The C-Beam environmental roof was designed, constructed and tested according to South African standards and methods. The following is the detailed methodology:

(a) Precast prestressed concrete C-Beam Design.

The existing design of C-beam was upgraded to carry mor loads (plant pots full of soil). The design was done according to South African Bureau of Standards (SABS) 0100-01-1992 The Structural Use of Prestressed Concrete Design, 0100-01-1997 The Struatural Use of Concrete Design and Precast concrete floor slabs manual (Gibson & Cairns of RSA 1997).

(b) Construction of the C-Beams was done according to SABS 0100-01-1992 The Structural Use of Prestressed Concrete Design, 0100-01-1992 The Structural Use of Concrete Design and SABS 82:1997 Bending Dimension and Scheduling of Steel Reinforcement for Concrete.

(c) Testing the C-Beams was done according to standard testing methods like the Technical Methods for Highways (TMH1) and SABS 0100-01-1992. Questionnaire papers were developed to interview people in villages to test viability of the C-Beam environmental roofing system. Appendix 2 and 3 refer.

(d) The C-Beam environmental roof construction manual was compiled based on SABS 0100-01-1992.

1.5 BENEFITS

Greening Rooftops ... Why Not?

For the success of "Greener Rooftops," the benefits and importance need highlighting. Unfortunately, most people are conventional in their ideas of what a typical house should look like, the redbrick walls and the tiled roof. To change peoples' opinions of the ideal home, we have to educate them on the immense benefits of environmental enhancement such as with a green roof.

If a person in a high-density low-income area is encouraged to convert his already existing roof to a flat green roof-top, then a question which might be asked is the houses in the low-density areas do not have greenery on them, why should mine?

This thesis focuses on the benefits of green roofs in high-density urban areas. If we want to encourage people living there to change their attitudes toward the idea of an ideal home, then the low-density high-income areas must first become showcases of the ideal home.

Unfortunately, people who occupy these high-density areas have either come from the rural areas or their parents have. Many of them associate grassed roofs with the mud rondavels that they left behind in the rural areas. It might be that such communities view the idea of greening their roofs as a step backward rather than a step forward. This is because the home that one owns, regardless of his income should resemble that of the homes in which his peers and betters live.

1.5.1 Job Creation

South Africa is on the outreach to settle the problem of homelessness and clearing people living in the streets. Settling the problem of homelessness does not seem to solve the problem of people living in the streets. People taken from the streets and given homes will certainly go back to the streets because of lack of jobs. An elevated crime rate is contributed to by joblessness. The main cause of these is probably idleness and lack of job (finances).

This study attends these problems directly and/or indirectly. Construction of the C-Beam will provide jobless owners with some work to do and skills to use in future.

It is obviously not a good idea for every household to have their own construction materials, which they will use once in their life. One option could be that equipment be owned and hired out by the municipality - materials like scaffolding, shuttering materials, etc. The municipality can then monitor the use of this equipment, as well as being responsible for construction and safety seminars to the community.

Roof slab: Construction of a C-Beam environmental roof made of lightweight C-Beam units (150kg/unit) whose hand lifting, assembling, jointing, waterproofing and screeding can be done by people.

Taking care of the plants: plants will need to be taken care of in many ways - watering, weeding, fertilizing, etc. will be needed continuously. These plants may be vegetables for food for the family where surplus can be sold; or if it be flowers, they could be taken to the market for sales.

Even though the construction part of the job comes to an end at some point, the rest of the work like greening the rooftop and taking care of plants are continuous.

A do-it-yourself concrete rooftop slab construction and an extended rooftop garden can positively affect lifestyle, job creation and the national economy.

1.5.2 Health Benefits

Covering a rooftop with vegetation benefits the house owner/community in several ways things. Environmentally, by covering the rooftops in urban areas with vegetation one has increased the amount of biomass within the area. This means more vegetation to decrease the large amounts of carbon dioxide produced within the urban areas by cars, industries and other carbon dioxide producers.

Breathing clean oxygenated air is easier on the respiratory system, which in turn is essential for

good health. Vegetation on roofs will help in re-oxygenating the surrounding air through the process of photosynthesis, transforming carbon dioxide in the presence of sunlight to oxygen.
It was initially thought that the ozone layer was being reduced gradually all over the globe. In 1985, however, further research revealed a growing ozone hole concentrated above Antarctica. Fifty per cent or more of the ozone above this area of the earth was being depleted seasonally (beginning each October). Thinning of the ozone layer exposes life on earth to excessive ultraviolet radiation that can increase skin cancer and cataracts, reduce immune system responses, interfere with the photosynthetic process of plants, and affect the growth of oceanic phytoplankton. Because of the growing threat of these dangerous environmental effects, many nations are working towards eliminating the manufacture and use of chloroflurocarbons (CFCs). However, CFCs can remain in the atmosphere for more than 100 years, so ozone destruction will continue to pose a threat for decades to come.(Frescura, 1991)

A study conducted at National Aeronautics and Space Administration (NASA) for their space laboratories, found that even a single fig tree could purify up to ten cubic metres of air per day. (McMarlin, 1997)

Even when the air is clean, but if it is dry, that air can be difficult to breathe, this is because there is no moisture in the air. Moisture on vegetation produces evaporation that makes the air much easier to breathe and helps in cooling the surrounding areas.

The built-up areas within an urban area cause a microclimate to form. The removal of the vegetation and the increase in reflective surfaces cause the ambient temperature to rise. This is why it is easier to breathe in rural areas where there is more vegetation. The vegetation absorbs the sun′ s harsh ultraviolet rays and reduces the amount of radiation heat reflected off the surface of the earth. In some cases, the temperature in a forest can be up to fourteen degrees Celsius lower than the temperature of an urban area in the same vicinity. (McMarlin, 1997)

An increase in vegetation cover means a decrease in the amount of dust present in the atmosphere. Some breathing problems like asthma and certain allergies are attributed to dust that are constantly present in large amounts in urban areas. Reducing the dust content in the air by increasing the amount of vegetation in the area provides health benefits.

Flora acts as a medium or an air filter for dust. The dust is attracted to the plant leaves and sticks there until it rains. When it rains the dust particles are washed off down the stems of the plant to the ground. In certain parks the amount of dust removed from the air is up to as much as eighty five per cent less dust than that in surrounding areas.

It is therefore quite easy to see how the greening of the rooftops in urban areas will dramatically benefit the environment and therefore everyone's health.

1.5.3 Stormwater

Water is a precious resource and can no longer be regarded as a free commodity. Climatic conditions and seasonal changes largely dictate the amount of water available to a community. The world's climatic and seasonal conditions are becoming more erratic.

The trend over recent decades has been a migration from the rural to urban areas. This has caused serious changes in the natural water cycle as mentioned above. Urban areas have a great deal of their surface area covered with impenetrable surfaces such as roads, concrete areas, parking lots, buildings and their roofs etc. These surfaces all contribute to the high run-off. A typical tiled roof obviously produces a one hundred per cent run-off during precipitation.

Extensive research has taken place on how to reduce the amount of run-off from an urban area by using greened roofs. As much as fifty per cent run-off reduction was assured by means of the grass roofs. (Smith, 1997

The greening and flattening of roofs has a major advantage in that it reduces the initial peak out flow of a storm in an urban area. One square metre of green roof has the water saturation time varying between few minutes to several hours. This obviously is dependent on the thickness and the type of greened roof layer and the intensity of the storm.

The delay in stormwater run-off reduces the overall cost of the stormwater drainage system installed for a community. The delayed stormwater run-off allows for smaller diameter pipes in the drainage system. Without this delay, pipe sizes of greater diameter would need to be installed to cope with the immediate peak volume of stormwater run-off.

The use of heavily designed pipes is highly inefficient because a pipe can only flow at its full potential for a relatively small part of its design life. By reducing this initial peak stormwater drainage systems become more viable.

The stormwater from a high-density area tends to be rapid, and can be destructive if not controlled. Most stormwater systems direct the flow of water toward a natural water flow like a river. Naturally rain that falls in the area would run-off the land and end up in a river. The problem comes when the area is developed. When the land is developed into a high-density area, the rain that falls cannot infiltrate because of the impenetrable man-made surfaces. This results in more of a rainfall running off the land into stormwater systems. The stormwater system now discharges the water into rivers. The river cannot handle the large amounts of water that the stormwater systems have deposited and start eroding the riverbed. Plant life and fish are disturbed and can no longer live in the river system.

By converting the existing and future roof to flat grassed roofs, the peak amount of water that enters the stormwater system at one time is reduced. This has ecological benefits further down stream.

1.5.4 More Space

At the moment the current roofs have two major disadvantages; firstly they are not environmentally friendly as discussed above, secondly they are not accessible. This is a huge waste of valuable space. In the high-density areas the emphasis is on cost, which is directly related to area. The bigger the area each house occupies the more expensive the housing project. This is all quite obvious, so why then do we not utilise the area to its full potential. The roof occupies a large percentage of the plot area yet this roof area is not used.

If the roofs were converted from their traditional pitched design to a flat accessible roof, the amount of usable area almost doubles. The question may be asked, the area of the roof is small and will not greatly increase the amount of usable area that the owner has, is it worth the effort? The answer to this question is yes it is definitely worth the effort. People in high-density areas do not have much space around their homes to establish a garden. The roof provides an ideal location for a garden.

1.5.5 Socially

The flat roof provides a safe place for the children to play during the day. At the moment children have to play in the streets around their homes and this is unsafe. The flat roof provides recreational benefits to the working adults as well. At the end of a long day work they can relax on their rooftop garden. The roof top garden can be used for social functions like braais (barbecues) and other events. This all improves the occupants' standard of living.

1.5.6 Source of Income

The flat rooftop can be used as a vegetable garden to grow vegetables and other fresh foods for the home. A surplus food produced could be sold to provide an extra income for the home. Various types of plants could be planted to generate income for the family, for example, flowers which could be sold. If a door size area ($2m^2$) can provide enough for one person, then there may be a surplus from a rooftop for a household. (Clifford – Community infrastructure 1999)

1.3.7 Aesthetics

A roof is considered to be serving its purpose as long as it does not leak and provides shelter from the elements. This has led to the roofs on our homes being the least attractive part of the building, because the roof can only be seen from above, and therefore does not concern the occupants. (McMarlin, 1997)

In the past several years, attempts to improve the aesthetic qualities of the home have lead to the increasing popularity of greened roofs. Fortunately people are becoming more aware of the environment and towards protecting the environment. Major steps are being taken to become more environmentally conscious about the use of ozone-friendly products and recycling of materials. It has become fashionable to be environmentally aware.

1.5.8 Security

Security is a major problem in South Africa, especially in the high-density areas. Crime is on the increase and most South Africans feel unsafe.

At the moment breaking into houses using the roof seems an easier option to robbers. Such cases are often reported on media. The existing roofs consist of corrugated iron sheeting, which can be easy to remove and gain access into the home. By converting the existing roofs into roof gardens a concrete slab will be used as the roof. The concrete roof, soil and vegetation will make access via the roof more difficult and help improve the homes' security

This provides security for children playing on the roof as opposed to playing in the streets where there is often car accidents, shootings, kid-napping, immoral behaviours of the passers by, etc.

CHAPTER 2

LITERATURE STUDY

2.1 Introduction and Overview

Many researchers report on a desperate need for the reclamation of nature by greening the land around the homes. However, apart from the current research there has been almost no reference to the concept of greening the roofs, especially for domestic homes.

Many researchers also report on the importance of an economical prestressed concrete design and construction. Strengthened (precast prestressed concrete units) flat roofing can be used in greened roofs to sustain the imposed loads.

2.2 Literature Review

Several textbooks and internet sites refer in general to the benefits of green roofs, (e.g. Lawrance 1997, McMarlin 1997, Bauder 1998; etc.). The following reviews make relevant reference to this research.

2.2.1 Environment

Clifford (1996), Young & Clifford (1996), Clifford (1997) on Community Infrastructure Research Program suggest that the quality of life of those living in cities is usually restricted by a number of things but especially its isolation from nature. Cities are also intrusive on nature as large areas are paved, causing significant run-off of rain water. Heat build-up over cities caused by large areas of paving and roofing also affects the natural environment.

Lawrence (1997) has written his master thesis on roof gardens. He concluded that; "agricultural production practices must be dictated to be a local environmental context." He found that the best way to conduct his study was to work and maintain a roof garden.

Muir (1998) in his project, Enviro Roofs, concluded that roofs cover the majority of the area in high-density areas. A pitched metal-sheet roof produces 100% run-off, not only causing local problems, but problems further on down stream.

McMarlin (1997) illustrates the practical and aesthetic benefits of greening one's rooftop. He discusses how greening the rooftop can benefit the environment and increase the aesthetic appearance on the building.

Kuhn (1995) were involved in promoting "Green roofs." They state: "Rooftops are a city's greatest untapped resource." They explain the many benefits of a roof garden and basically how to construct and manage a "green roof" as a resource. They note that countries such as Germany and Switzerland have promulgated legislation to 'green' the roofs.

Walsh (1998) studied Enviro-Roofing and found the benefit of a greened roof to be pleasing on the eye with a relaxing atmosphere. He reports 'we could be an entrepreneur and have our own business in our own back yard/rooftop. We could either make money from our cultivating of crops or growing of flowers or supply our family and possibly our neighbours with fresh vegetables'.

Theunissen and Clifford (1999) delivered a paper on successes and challenges: some real examples of incorporating the environment assessment in urban environment. They commented - prior to the introduction into South Africa in 1989, of guidelines for the process of integrating environmental concerns into development actions, and the more recent legislation for compulsory environmental impact assessments (EIA), any responsibility for the utilisation and protection of the full range of environmental concerns in project, was left to the discretion of developers, planners, and local authorities, with the advent of the European Industrial Revolution and the need to house workers as close as possible to factories, urban development rarely include greenery.

The Environment Conservation Act 1989 (Act No. 74 of 1983), 3.2.2. Regulations No's 1182, 1183, 1184 dated 5 September 1997 - states that in terms of these regulations it is now a legal requirement to perform an Environmental Impact Assessment for virtually any development when read in conjunction.

2.2.2 Prestressed and Reinforced Concrete

Mosley & Bungey (1990) studied the advantages of hollow floor slabs and discovered that the reduction in weight is achieved by removing part of the concrete below the neutral axis under tension.

Gilbert & Mickleborough (1990) studied the advantages of prestressed concrete members over reinforced concrete members and concluded that prestressing results in lighter members and hence an increase in the economical range of application of reinforced concrete.

Wilby (1983) studied the advantages and disadvantages of prestressed concrete members and concluded that the chief advantage of prestressed concrete is in reducing the quantities of steel and concrete required and in eliminating or reducing the widths of cracks. He continues in that, prestressing strengthens a beam in shear and can give a useful saving in shear reinforcement, useful with regard to the final cost of the concrete member.

Faber & Alsop (1979) studied floor units and concluded that precast prestressed concrete units are made with cross sections that serve to keep the dead weight of the unit down whilst still achieving an over-all depth sufficient to avoid excessive deflection. Such units would weigh about 55 per cent of a solid unit, yet the strength and stiffness requirements are adequately met. This saving makes prestressed units more economical.

Morrell (1989) conducted a study on prestressed concrete construction and concluded that speed of erection is one of the most important attributes of precast prestressed concrete units because it does not require propping. Thus, work below the slab can proceed immediately without interruption. In addition, when the joint concrete has hardened, a working platform is available for construction to proceed above. This brings about a significant saving in time and cost as compared to simply reinforced concrete.

Gibson & Cairns (1997) compared different types of precast prestressed concrete unit systems, and commented that prestressed concrete reduces the mass of concrete in the slab, with a reduction in foundation loads and possibly slab depth as a result. The soffits are suitable for decoration with the minimum amount of preparation work, and this makes a considerable saving from reinforced concrete units.

Ramaswamy (1976) conducted a study on prestressed versus reinforced concrete and concluded that, in prestressed concrete, the entire concrete section is active in resisting the load, while in reinforced concrete only the uncracked part of the section is active. Because of this, prestressed concrete members are lighter, more slender, and aesthetically more appealing than their reinforced concrete counterparts. The above attributes of prestressed concrete member render it more economical than reinforced concrete member.

Reynolds (1938) researched on concrete construction and commended about the popularity of hollow clay tile and other forms of hollow floor slabs, due to their economy and light weight after.

Reynolds (1939) studied the strength of hollow slabs and concluded that if spans of the slabs between the beams exceed 3m, it is more economical to provide hollow core slab that is light in weight and uses less concrete.

Abeles & Bardham-Roy (1981) studied the economics of prestressed concrete and concluded that a prestressed member, when compared with an equivalent reinforced concrete member, requires less concrete, and about a fifth to a third of the amount of steel; but the difference in initial cost is not proportional to the difference in weights of materials. Steel as well as concrete in a prestressed concrete member, needs to have high strength and high quality. The unit costs of such steel and/or concrete are higher than those of the materials required for reinforced concrete construction. Formwork or moulds may by more expensive, and the additional cost of the prestressing operation itself must be considered. However, in general, there is little difference between the initial costs of reinforced and prestressed members, provided that large numbers of precast prestressed units are required. On the other hand, the indirect savings that accrue from prestressing are often substantial and should be taken fully into account. They include the reduction or total avoidance of maintenance and the longer working life due to the greater durability of the material (arising from the absence of permanently open cracks), the reduction in the dead weight imposed on the supporting members and foundations and reductions in the structural depth of members.

Kong & Evans (1975) studied prestressed concrete slabs and concluded that it is economical to reduce concrete the tension zone except that which is holding the prestressing bars and make the slab/beam lighter.

Hurst (1986) studied prestressed concrete design and concluded that one of the main advantages of prestressed over reinforced concrete is that, for a given span and loading, a smaller prestressed concrete member is required. As well as a saving in concrete material for members, there is also a saving in foundation costs, and this can be a significant factor in areas of poor foundation material.

Buettner (1985) describe a precast prestressed hollow core concrete unit as a concrete member with continuous voids provided to reduce weight and, therefore, cost and as a side benefit, to use for concealed electrical roof deck systems. When stating the advantages of a hollow core slab, they say, 'hollow core slabs are most widely known for providing economical, efficient floor and roof system'.

Chalatse (1998) in his Btech project, The C-beam design, excludes the topping to eliminate among other things, the problem of designing with an allowance for horizontal shear. The inclusion of topping adds to the overall cost of the unit.

The following are the studies and comments as well as recommendations regarding cost effect of horizontal shear as it should be designed for if topping is to be included.

Gibson & Cairns (1997) developed a design manual for a composite beam and concluded that, in shallow members topping makes a significant difference in cost compared to members without topping because of extra design for horizontal shear, extra amount of material (concrete and steel) and propping.

Naaman (1982) studied analysis and design of composite beams and commented that, in practice, it is difficult to accurately predict deflections in composite beams construction where two different concretes of different properties and ages at loading ate used and where composite action is achieved only after a certain time. In addition, the restraint provided by the cast-in-place slab can cause increases in the prestress losses of the precast element and thus influences time-depended deflections.

Gilbert & Mickleborough (1990) studied the effects of horizontal shear and concluded that, the ability of the entire composite member to resist loads depends on the ability to carry horizontal shear at the interface between the precast and *in situ* elements, and if the two components are not effectively bonded together, slip will occur at the interface and the two components will act as separate beams each carrying its share of the external loads by bending about its own axis. They finally stated that this is not a cheap exercise.

Abeles & Bardhan-Roy (1981) studied composite beam design and concluded that, a delegate stage in the design of a composite beam is to make concretes of different grades and different ages to work together without slipping under loads (horizontal shearing). They commented that this stage in composite beam design makes is cost more than beams with no topping.

Hurst (1986) studied composite construction and recommended no topping for shallow members because there is usually no mechanical key between the two types of concrete. Reliance is made on the friction developed between the contact surfaces. This makes such concrete members expensive and dangerous because horizontal shear may result and the beam may not successfully carry the loads.

Morrell (1989) studied the effectiveness of shear connectors and commented that, if the section is made up of materials with differing moduli of elasticity, this results in differential strains being developed, and movement of one material of the section relative to the other, so that the section ceases to act as a homogeneous whole and failure may result. This makes a slab with topping to be too expensive.

2.3 Conclusion

Several researchers from different parts of the world, doing their researches at different times come to the same conclusion that there is a need for greened (environmental) roofing. Environmental conditions in South Africa in general require a lot more attention and improvement, hence the Environment Conservation Act 1989 (Act No. 74 of 1983), 3.2.3 Regulation No's 1182 – 1184. This Act forces every development to do an Environmental Impact Assessment and comply with it (the Act).

Greening rooftops improves environmental conditions in cities and townships where it is needed more.

It is a project worth adventuring because it doesn't only comply with the legislation but it is also a need for people living in cities and townships for improved health.

Introduction of the C-Beam Environmental Roof that is made up of a light-weight prestressed precast concrete units placed at a shallow slope ((3%), and greened top is a product that needs to be exploited at times such as this.

CHAPTER 3

C-BEAM ENVIRONMENTAL ROOF EXPERIMENTAL PROCEDURE

C-beam construction and a few tests were done to determine its viability. The following tests were undertaken:

(a) The structural stability and suitability of the beam.

(b) The C-Beam concept:

(i) A questionnaire survey on communities concerning the C-beam concept.

(ii) A questionnaire survey on communities concerning staying on the roof.

3.1 C-BEAM CONSTRUCTION

3.1.1 C-beam properties

Description	Prestressed concrete beam with a cross sectional shape of a 'C'
Cement	CEM I 42.5 complying with SABS 1997-1
Water/cement Ration	0.53
Aggregate	Dolerite stone between 6.7 mm and 9.5mm)
Concrete workability	Slump ranging from 60 mm to 100 mm
Concrete compressive strength	30.0Mpa
Prestressed tendons	3.2 mm diameter wires, with characteristic bearing load of 25kN/m^2
Minimum cover to bottom steel	20 mm

Figure 3.1 below shows a section of the C-Beam

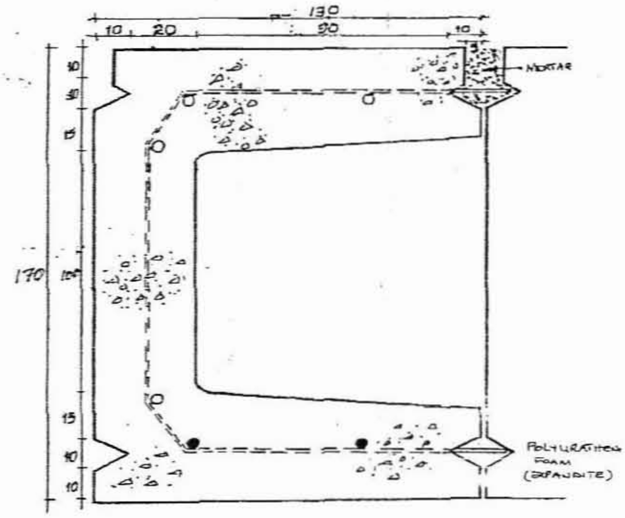


Figure 3.1

3.1.2 Material properties

(a) Formwork - Due to economic reasons the formwork was made out of V.P deck boards and T & G floorboards. Screws and wood glue were used to hold formwork pieces together. The formwork was assembled with the 170 mm side of the C-Beam open (stranding on flanges) to facilitate concrete pouring.

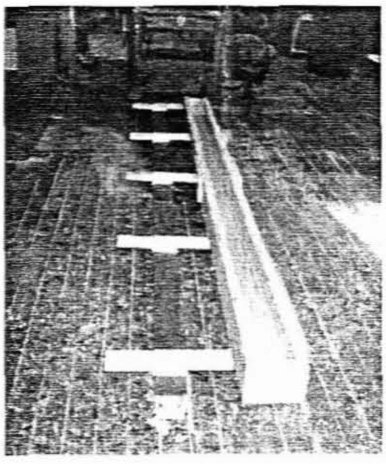


Fig 3.2 - C-Beam Wooden formwork

(b) Prestressed Tendons - The minimum cover to the bottom prestressed steel was set at 20 mm. The three bottom wires were prestressed to 75 % of their ultimate capacity by the stressing bed.

(c) Concrete - Concrete was a mixture of cement, river sand, crusher dust, cement and crushed stone

3.1.2 Concrete Mix Design

Material/Item	Mix Number			Units
Concrete Mix	1	2	3	
Design Concrete Strength	30	30	30	Mpa
Cement (RHPC)	450	404	452	kg/m^3
Water	170.5	210	235	l/m^3
Stone (6.7 - 9.5mm)	1100	1150	715	kg/m^3
Building Sand	680	0	645	kg/m^3
Crusher Dust.	0	860	325	kg/m^3

Table 3.1 Mix designs 1 to 3

3.1.4 Preparation of the mould for concreting

1. The inside of the formwork was oiled to facilitate stripping
2. Steel was placed according to the design drawings. Stirrups placed at 150 mm centre to centre.
3. The mould was placed on a prestressing bed then wires were prestressed to their design prestressing degrees (75%) as mentioned above.

3.1.5 Concrete Mixing

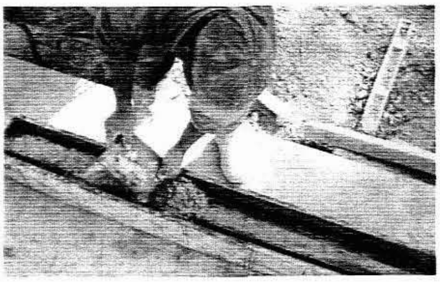
Mixing of concrete was the same for all three mixes, using quantities shown on the table 3.1 above. The mixing was done by hand. From each mix, nine concrete cubes were made from 150 x 150 mm moulds (three cubes per test). Sampling and testing was done according to SABS 0100-01-1992.

Cubes were then stripped after 24 hours and placed under water at 25°C until their respective crushing dates.

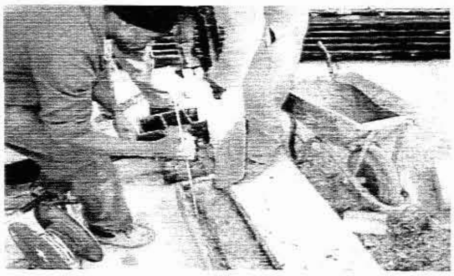
Fig 3.3 - Making concrete cubes

3.1.6 Placing of Concrete

Concrete was then poured in the C-Beams casting moulds in three layers and each layer compacted by a tamping rod. Each layer's compaction was assessed visually. A trowel was then used to give a fine/smooth finish on the open surface.

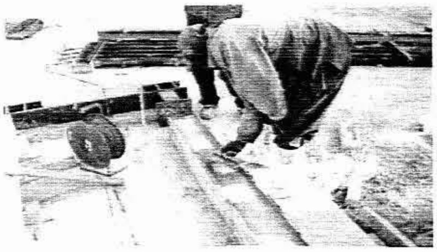


(a) placing of concrete in moulds



(b) compacting concrete in moulds

Fig 3.4 pouring, compacting and finishing of concrete in C-Beam moulds



(c) finishing open ends of concrete

3.1.7 Cutting of Wires, Stripping and Curing

The concrete was allowed to cure in moulds for 24 hours, then stripping of the shutters took place. The prestressed wires were cut at both ends of the beam after stripping. Beams were then removed from the prestressing beds, placed on a flat ground in their loaded position, and covered with sack cloths (moisture retaining cloths). Thereafter the cloths were wetted. Beams were made to cure under wet cloth for seven days.

3.2 TESTING THE C-BEAM

The structural stability of the beam was tested and it which included the following:

(a) concrete compressive strength
(b) cracking
(c) handling
(d) deflection
(e) interlocking
(f) waterproofing

The C-Beam concept was also tested by a survey to some communities about changing from conventional pitched roofing to the C-beam type of roofing. And thirdly, a test on sampled people about staying on the rooftop.

3.2.1 Structural Stability of the C-Beam

(a) Concrete compressive strength - Concrete cubes were made from concrete used for casting C-beams to be tested for the concrete's compressive strength.

(b) Cracking - Cracking was determined by means of visual inspection. Beams were inspected after removal from the moulds, after handling and transportation, and after being tested for deflection. The size, length and location of cracks were taken to assess different levels of damage caused by each one of the activities (shrinkage, handling and loading).

(c) Handling - Different handling and lifting methods were done to determine the safe way of transporting C-beams from one place to another and from the ground to the rooftop. The following are the handling methods used:

(i) *Generally* - before lifting, the beam was inspected for damage. All cracks existing on the beam were noted. This allowed accurate determining of which activity caused cracking.

(ii) *Method 1: Hand-lifting* - Three men, one at each end and the other in the middle lifted the C-beam against their waists as shown on figure 3.5 below.

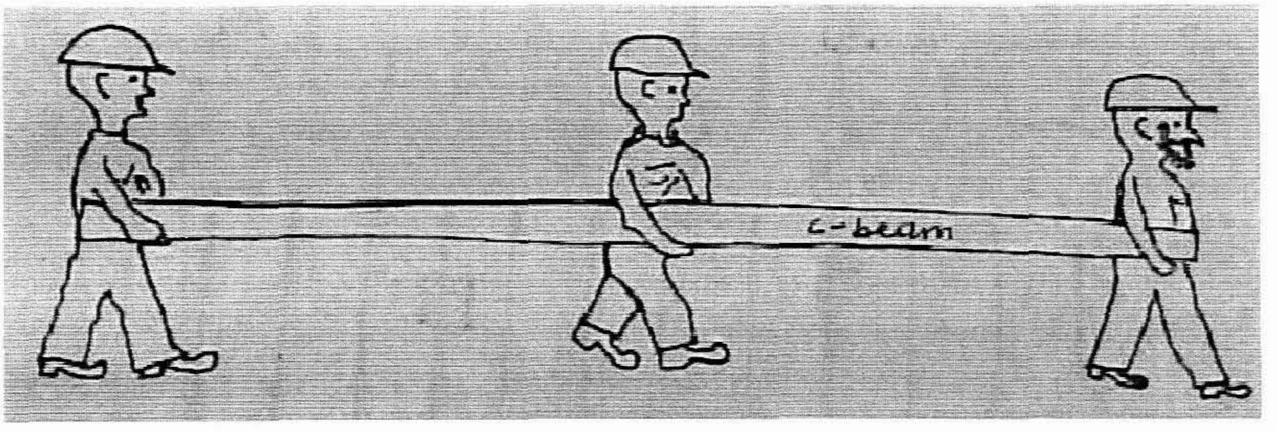
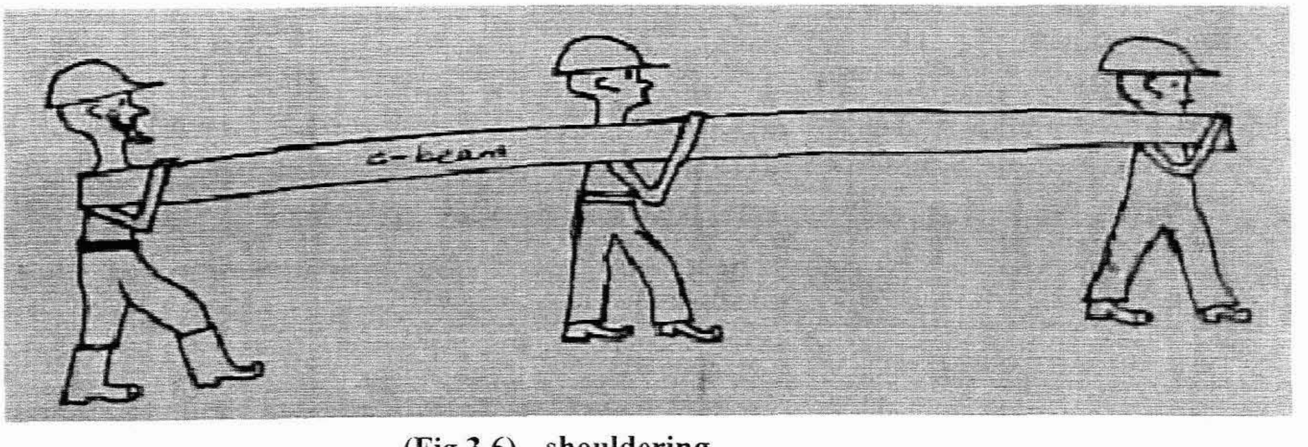


Fig 3.5- hand-lifting

(iii) *Method 2: Shouldering* - Three men, one at each end and the other in the middle of the beam lifted the C-beam to their shoulders and shown in figure 3.6 below.



(Fig 3.6) - shouldering

Safety in handling, lifting and placing was an important factor in the whole test, and it is discussed more in the C-beam construction manual. Beams were lifted using methods 1 and 2. Lifting and holding beams at different positions were done to determine suitable and convenient ways and positions of holding and lifting C-beams. Beams were inspected for cracking before and after every lifting/ holding method and position. The following are the positions tested:

(i) C-beam roofing position - The beam was hand-lifted and shouldered with its roofing position at the bottom, i.e the way it would sit on the roof.

(ii) Handling the flanges - A beam was lifted with hands gripping on one of the flanges and the rest of the beam section hanging.

(iii) Flanges facing downwards - A beam was carried by three men against their waists, with flanges facing down and gripped by one hand on one flange and the other hand on the other flange. Shouldering method was tried in this position too. The one flange rested on the shoulder facing down and the other was supported by the lifter's hand.

(vi) Flanges facing upwards - The two handling methods were used on this position. Beams were lifted from the ground lying on their 170 mm side by hand to the lifters' waists. Lifters moved with their hands wrapped around the beam. On placing the beam on the ground, they turned it to its sitting position by first suspending the rest of the beam section to one flange then to the ground/floor. Using the shouldering method, the beam was lifted by hand from the ground to the lifters' shoulders, then movement started. On laying the beam on the floor it had to hang on one flange and land on the other.

(d) Deflection - The total loading that the C-beam was exposed to is summarised and put together for the purposes of testing. The following is a brief calculation of the loading:

loading condition for an accessible roof = 2.0 kN/m^2
load of finishes = 1.0 x 0.13 (beam width) = 0.13 kN/m
live load = 2.0 x 0.13 = 0.260 kN/m
load of plant pots - taking three, 200 mm diameter at 3.0 kg/m length of a beam

Load Calculations:

pots: 3 x 3 = 9.0 kg/m → 0.090 kN/m
finishes = 0.130 kN/m
live load = 0.260 kN/m
0.480 kN/m
48 kg/m total load on beam (use 50 kg/m)

The deflection test was done on individual beams. A simply supported set-up was arranged for the test as shown in figure 3.7 below. Beams were inspected for cracks before the test. A beam was placed on a simply supported set-up spanning 4.0 m. Weight equivalent to the one that beams will be exposed to (50 kg/m) was placed on the beam. The test load was sustained for a period of 24 hours with deflections and crack widths observed before application, after 24 hours but before removal of loads, and after removal of loads. A string was attached on the beam supports below the beam. Measurements were taken by Vernier calipers between the beam and the string at 1.0 m, 2.0 m and 3.0 m distances from each end before loading and after 24 hours. The recovery thereof was also measured.

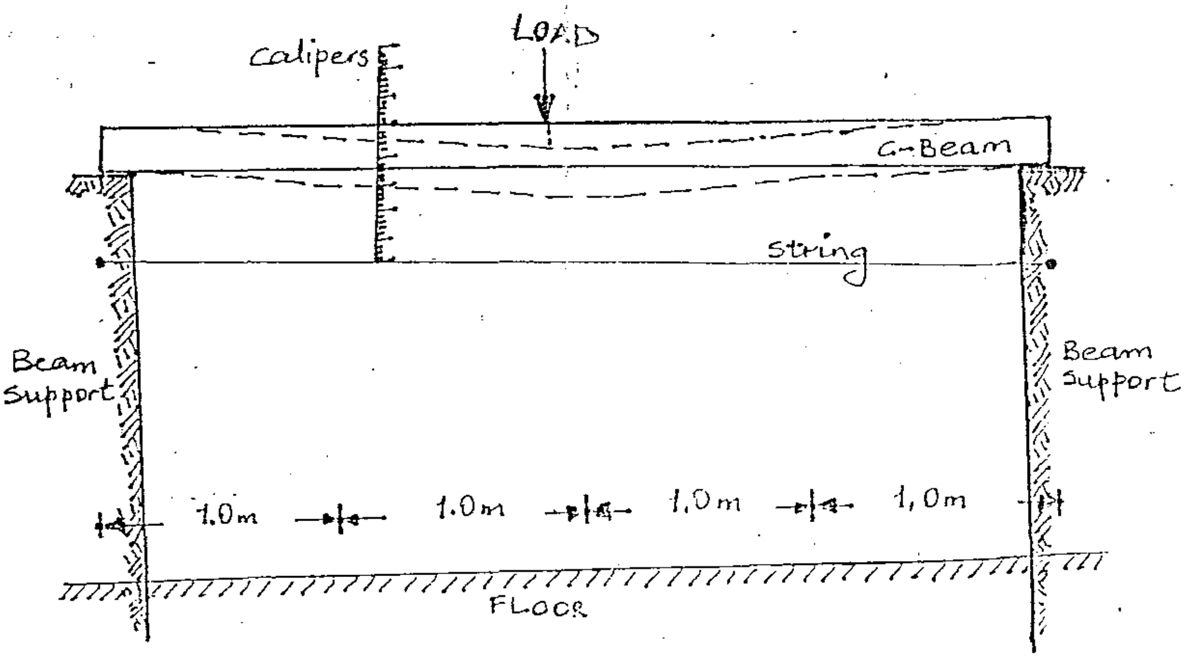


Fig 3.7 - deflection test

(e) Interlocking - Beams were placed alongside each other on the supporters and their alignment was checked. Joints were inspected for openings or holes that could lead mortar through.

(f) Waterproofing - The waterproofing of the C-beam joints and the slab as a whole involved a few stages and some tests. The following are the stages pertaining to waterproofing of the slab:

(i) Jointing - All joints were inspected after placing for proper placement, proper interlocking and good placement of shear links in the grooves. Where interlocking and placement were found improper, they were put right.

(ii) Joint preparation - The inside faces of the joints and projecting reinforcement (shear links) were inspected for cleanliness. Dust that had accumulated in the joint was blown using compressed air blower from one end to another. Oil from faces of the joint and the shear links was removed using a cloth and soap. Where soap was used the faces and/or reinforcement were rinsed with clean water.

(iii) Mixing, Application and Tooling the Sealant

Mixing - Three parts of sand to one part cement by mass were mixed. The past was prepared such that it does not become so wet that it bleeds through the joints to the bottom of the beams; and that it does not become so stiff that it becomes difficult compacting through the bars and the corners of the joint. Mixing was done on the ground and mortar transported by a bucket to the rooftop.

Application - The clean joints were wetted lightly before the application of mortar. The mortar was then worked in the joints by a building trowel. Building trowels were used to tap and compact the mortar into the corners of the joints. The mortar in the joint was worked to the approximate levels given on the drawings. The joints were left to cure under water for three days. They were watered three times a day - in the mornings, mid-days and in the evenings.

Tooling the Sealant - Inspection of the joints for cleanliness and minor cleaning were done before sealing. Joints were allowed to just dry before the application of the sealant. A polyurethane sealant was applied directly on the mortar in the joint. The sealant was packed in bottles with nozzles and spray buttons to pump out the sealant. Polyurethane was applied to the joints as close as possible to the drawings instructions. Figure 3.8 below shows a detail of a C-Beam joint.

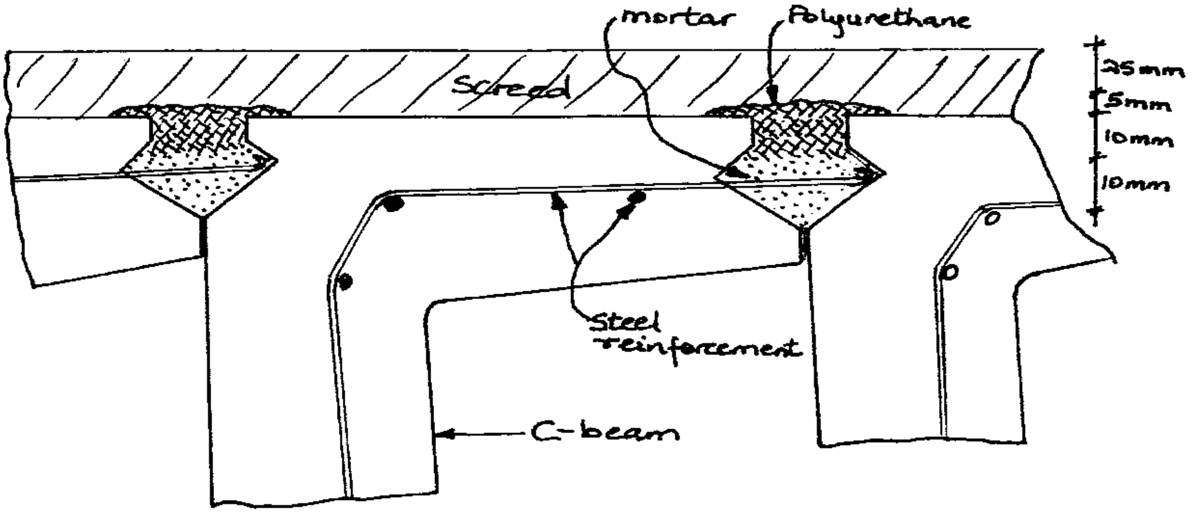


Fig. 3.8 - joint filling detail

(iv) Base Preparation - All loose material like cement/mortar patches on the surfaces of the roof were scraped off carefully not to detach the sealant. Dust and dirt were washed away by water while oil and other contaminants were removed by a cloth with soap then rinsed with clean water. The base was then allowed to dry.

Absorptiveness test - The absorptiveness of the base was then tested as follows: A cupful of water was poured on the base and a few minutes later (between 5 and 10 minutes) the water remaining was removed.

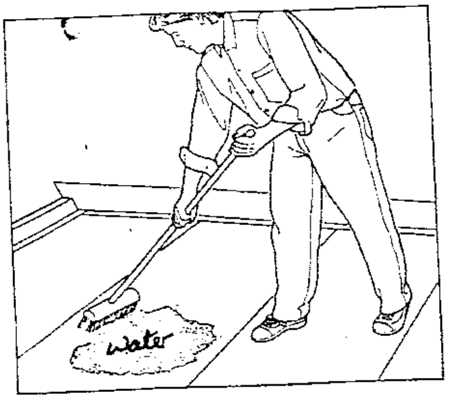
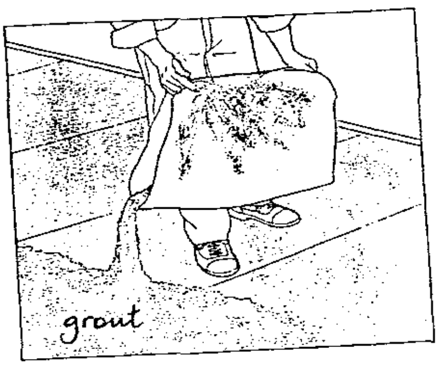


Fig 3.9 - absorptiveness test

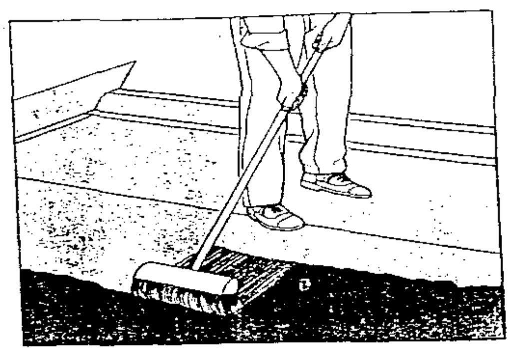
(v) Screeding

Grouting - A watery mix of one part sand to one part cement by mass was prepared and applied on a clean and dry concrete base (slab). The grout was slashed on the area where it was needed, and then worked thoroughly onto the surface of the concrete by scrubbing with brushed and then brushed out to leave only a thin coating on the base without leaving pools of grout in depressions.

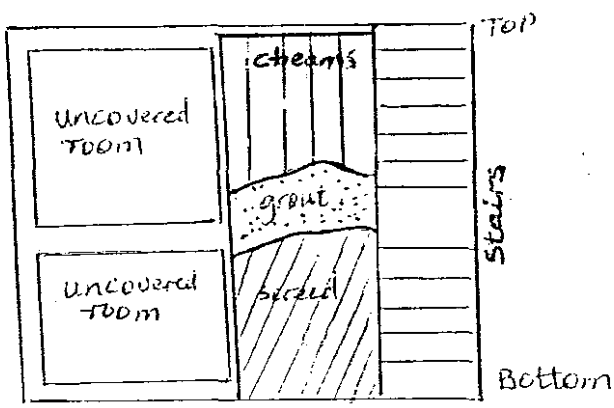
Screeding - The screed mix was prepared on the ground with two parts of crusher dust and one part of clean building sand to one part of CEM II cement by mass. Screed was applied to the grouted surfaces while the grout was still visibly wet, i.e within 10 to 20 minutes of grout application. Control levels were marked by fishlines running from one end to another in a slope of 3%. Mortar was placed, laid and compacted on the grouted surfaces. Compaction of the screed was done by tamping with a straight-edge and light timber screed boards operated by one or two men. Cutting to final levels was as well done by straight-edge. Figure 3.10 (a), (b) and (c) below shows stages of screeding involved in the construction of the C-Beam roof.



(a) Application of grout



(b) Spreading of grout



(c) Application of screed mortar

Fig 3.10 – (a), (b) and (c) screeding

Smooth Finishing - After two hours of screeding, light sprinkles of water was applied by the use of brushes onto the screed, then wood-floated to cut it to finer finish. Then while it was still wet after wood-floating, cement powder was also lightly applied on the surface and immediately worked on by steel floats to give a very smooth surface finish of 1.0 to 2.0mm thickness. The slab was left to stand overnight and the following morning the slab was cured.

(vi) Curing - When the screed was hard enough to leave no marks when walked over, a layer of clean sand of about 40 mm was laid on the whole slab and watered. Watering was done carefully not to wash way the sand. The sand was watered using watering-cans three times every day for seven days. It was watered in the mornings, at mid-days and in the afternoons. At the end of the curing period, the sand was heaped and removed from the roof. The rest was swept away using a soft broom not to damage the surface.

(vii) Damming - The slab was allowed to dry for seven days before it was tested for waterproofing. The whole slab was inspected for dryness before the test. Ten A4 paper sheets (labelled 1 to 10) were placed at different random areas of the slab soffit along the soffit joints. The soffit joints were not yet sealed when the test was done. Water was then dammed across the rooftop using clay. The water stood on the roof for 24 hours. Hourly inspections were on the papers for 8 hours to check their dampness. Half hourly inspection on papers for the next 6 hours; twentieth minute inspection for five hours; tenth minutes inspection for three hours; and fifth minute inspection for two hours. At the end of the 24 hours papers were removed and the water on the rooftop was removed.

(viii) Sealing the Soffit Joints - After the waterproofing test of the slab, it was allowed to dry for seven days then the soffit joints were cleaned by blowing compressed air from one end through to the other end. Polyurethane was then pumped into the grooves of the C-beams (joints).

(xi) Damming After Sealing soffit Joints - The same procedure as in (vii) above was followed with new and dry papers at the same positions with the same numbers. Results were also recorded.

3.2.2 C-Beam Environmental Roof Questionnaire

A questionnaire was developed and a survey was conducted in suburban areas of Cape Town, South Africa and Maseru, Lesotho. Any one township in the two cities was chosen, and any resident thereof was interviewed according to the questionnaire. Fifty people from one township in Cape Town and 70 people from one township in Maseru were taken as a sample. This test was done to get some feedback from people whether they like the idea or not. Appendix 2 shows details of the questionnaire.

3.2.3 Roof Garden Test

A group of ladies was taken as a sample to test the concept by walking up the staircase to the rooftop, walking on the rooftop, working on the roof garden and relaxing on the rooftop. Thereafter each member of the group was asked questions concerning activities that involved the roof garden. Appendix 3 shows details of the questionnaire. The roof garden at Cape Technikon's lecture halls (Figure 3.11) was used for the tests.

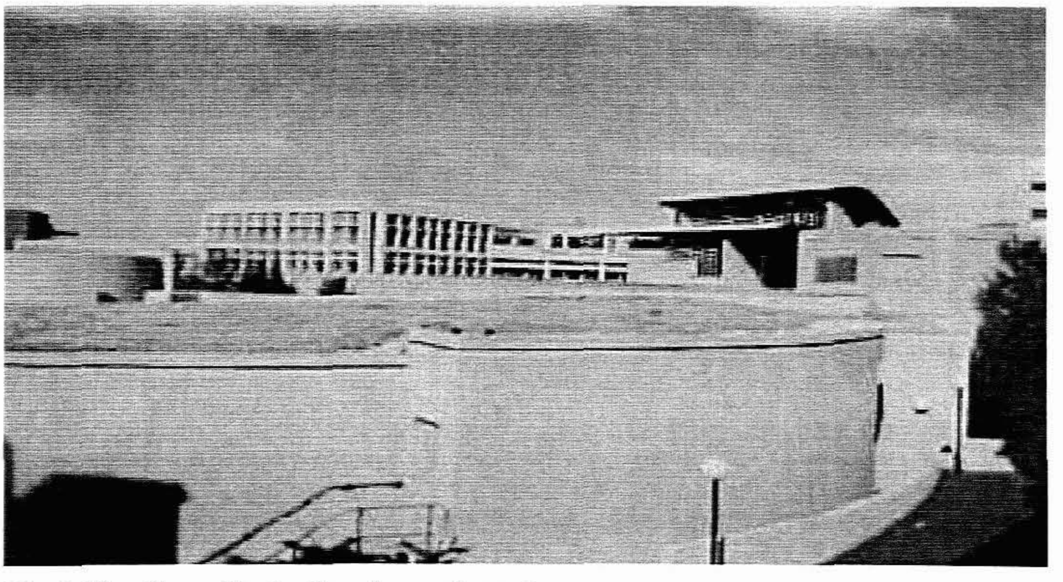


Fig 3.11 - Cape Technikon's roof garden

3.3 CONCLUSIONS

Three concrete mixes were designed with differences and similarities in components and quantities to determine the best concrete mix for use in casting the C-Beam. The casting mould was also made from South African pine boards, nailed and glued together. Prestressing bed with pretensioned wires was prepared together with the mould to receive concrete. Concrete of three different design-mixes was placed, stripped and cured. Samples from all design mixes were taken, cured and crushed to determine their respective compressive strengths at different concrete cube ages.

Prestressed concrete C-Beams from the three design mixes were tested for structural soundness. They all went through similar testing under similar conditions. Close monitoring was done when they went through the process of deflection, handling at different positions with different methods to determine the best methods and positions, interlocking, shock-action causing cracking on beams, and waterproofing.

The testing and construction of the C-Beam Environmental Roof were done according to SABS 0100-01-1992, TMH 1 and other standards.

The C-Beam Environmental Roof concept was tested by preparing a questionnaire and asking peoples' opinions on the idea of changing to the environmental flat roof. The concept was further tested by taking a group of ladies to walk up and down the staircases of the Cape Technikon's greened lecture halls, work and relax on the halls. After the exercise the group was asked questions to express their observations, feelings and opinions concerning the exercise in particular and the concept itself.

All the tests on the C-Beam Environmental Roof were done to determine the structural soundness of the beam and the viability of the concept.

CHAPTER 4

4.0 ANALYSIS OF TEST RESULTS

While chapter 3 basically comprises of C-Beam experimental and the C-Beam concept testing, this chapter is about observations of behaviour and conditions pertaining to the tests.

4.1 PRESTRESSING

Bottom wires were prestressed differently so that beams could have some camber to improve their load bearing capacity. On inspection beams lying on their operating position had some camber. A close inspection on beams of different mix designs revealed that their degree of camber is not the same: Mix 2 had the lowest camber and mix 3 had the highest camber. The following are the measurements taken from the floor to the soffit of the beams using Vernier calipers:

Mix 1 → 12.3 mm

Mix 2 → 11.2 mm

Mix 3 → 16.6 mm

The difference in camber is attributed to combination of aggregates. In mix 2 the reason may be shortage in fines. The well graded the aggregates the better the aggregate-to-steel contact, the more the camber.

4.2 CONTRETE STRENGTH

Concrete cubes were taken during casting of the beams, and crushed at different ages to determine the concrete compressive strength. All concrete mix designs were represented in the sampling and testing. The following are the results of the cubes at their respective ages:

Concrete Mix Design	Concrete Cubes Age and Strength in Mpa			
	7 days	14 days	21 days	28 days
1	18.2	29.6	33.7	36.6
2	12.4	22.4	25.6	28.2
3	19.7	32.1	37.8	41.2

Table 4.1 - concrete cube strength

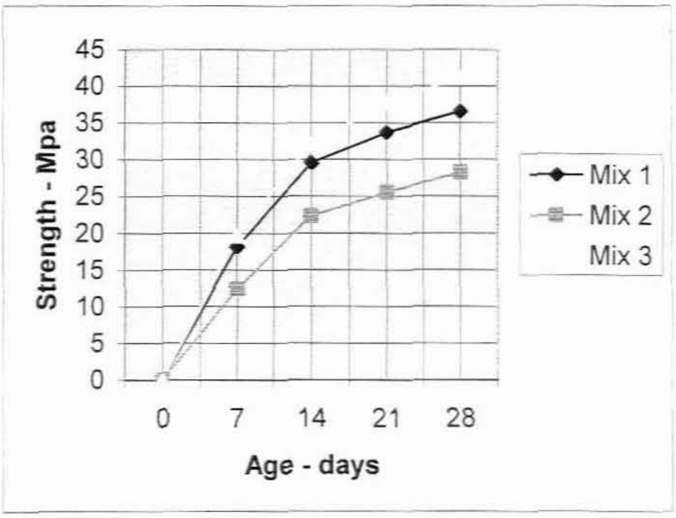


Fig 4.1 - Concrete Cube Strength

4.3 CONCRETE SURFACE INSPECTION

The surfaces of beams were smooth in texture (without honeycombing) showing reasonable compaction except for beams from concrete mix 2 where aggregates could be seen on the surface of the beams.

On beams in general some marks of air bubbles were noticed. Aesthetically the surface texture of beams from mixes 1 and 3 were acceptable good. During stripping, some beams got stuck on the formwork boards. On close inspection the formwork showed insufficient oiling.

4.4 CRACKING

On inspection a few cracks were noticed on some of the beams. Most of the cracks were very narrow and shallow (<0.1mm wide and < 3.0 mm deep) SABS 0100-01-1992. Figure 4.2 below shows one of the beams that had a very big crack, 2.0mm wide and 5.0mm deep, running longitudinally and near the corner of the C-Beam.

3mm wide and 5mm deep cracks along the corner of beam

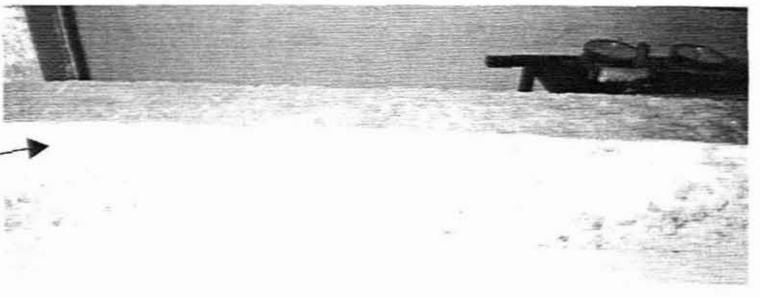


Fig 4.2 - wide cracks on C-beams

4.5 HANDLING

Observations on handling methods and positions of the C-beam were generally based on two things, namely the structural effect on the beam itself, and safety and convenience to the lifters.

(a) Structural Effect

On every method and lifting position, implications and effects of inducing stresses on certain parts of the beam were assessed; crack developments, effects and implications were evaluated; and damage for example, breaking or chipping due to lifting and/or placing was also under observation.

(b) Safety and convenience to Lifters

Safety is an important aspect in this project because materials handled are heavy and can cause serious damage and injury to property and workers. Though a broader scope of safety is discussed in the construction manual, a few elements were under observation in safety and convenience in these tests. The following were the areas of more concentration in regard to safety and convenience to lifters.

- Convenience of lifting
- Convenience of loaded movement of lifters
- Convenience of placing

The following are the lifting positions and their methods in the light of the C-beam's structural effect, and safety and convenience:

(i)-1. C-beam's Roofing Position With Hand-lifting Method.

Structural effect - The beams were inspected for cracks and damage before lifting. There were generally no widening and development of cracks after lifting. On some beams a little chipping occurred on the landing beam edge. This happened on incidences where communication between lifters did not word perfectly.

Safety and Convenience: lifting - it seemed easy to the lifters to tilt the beam from the top flange to allow hands to get under the beam for lifting. Three men, one at equal distances along the beam (one in the middle and others at the ends of the beam) comfortably lifted the beam to their waists.

Loaded movement - once the lifters had agreed to go forward, the movement seemed quite easy and comfortable to the lifters.

Convenience of placing - on placing the beam, the lifters allowed the beam first to land with the bottom corner of the web and then the flange. Communication between lifters seemed to facilitate a proper and careful placing of the beam.

(i)-2. C-beam's Roofing Position With Shoulaering Method

Structural effect - Beams were inspected before and after lifting for cracks and damages. There were neither widening of cracks nor developments of new ones noticed. On carefully placed beams, there were no chippings at the beams' edges.

Safety and Convenience: lifting - it seemed easy for the lifters to tilt the beam from the top flange to get one hand under the beam and lift it to one's shoulder. On observation, placing a hand at the right position on the beam to comfortably place the beam on a padded shoulder was relatively not as easy.

Loaded movement - once the beam was on the lifters' shoulders, movement to the next place was easier, quicker and comfortable seemingly.

Convenience of placing - the beam was placed first with the bottom edge of the web and then the bottom flange. Positioning of lifters' hands for unloading was also a bit difficult, but when lifters communicated well and waited for every one of them to have the right grip, placing of the beam became easy and safe

(ii) Handling Flanges By Hand-lifting Method

Structural effect - on inspection some beams had no cracks and some cracks were noticed during lifting when the beam was hanging from the top flange. These were longitudinal cracks on the inside of the top corner of the web and top flange. Cracks were not deep, and they closed up after placing. There were some minor chippings on the landing edge of the beam, and none on the more gently placed beams.

Safety and Convenience: Lifting the beam from the ground with the top flange seemed easy and comfortable to the lifters even when they used one hand each. Lifters had to hold tight to the flange for the beam not to drop on their legs and toes.

Loaded movement - moving with a suspended beam seemed fair but not very comfortable to the lifters.

Convenience in placing - the beam landed easily on the bottom edge. Some lifters used their other hands to facilitate gentle landing of the beam.

(iii)-1. Flanges Facing Downwards Position By Hand -lifting Method

Structural effect - There were no crack development on this method after lifting, transportation and placing. There were generally no damage and chippings on the landing beam edge.

Safety and convenience: Lifting - tilting the beams to have hands gripping on the flanges seemed easy. This position seemed to suit the method very well.

Loaded movement - movement to the next position looked comfortable.

Convenience in placing - on placing the beam, one hand was on one flange and the other supporting from the underside of the beam (the other flange), and the beam landed with the open end of the bottom flange. Placing here seemed comfortable.

(iii)- 2. Flanges Facing Downwards Position by Shouldering Method

Structural effect - The beam bore no structural defects as a result of lifting, transporting and placing.

Safety and convenience: Lifting the beam from the ground, tilting it to the right position and placing it on lifters' padded shoulders was not an easy process. Communication and coordination seemed very important to do it right and safely.

Loaded movement - movement to the next position was quite easy and fast, though the lifters seemed discomforted by the concentrated edge load of the beam flange on their shoulders. Lifter's heights seemed to have some influence on the convenience of loaded movement. The shorter one/s of the three men lifting the beam seemed to bear more load than the other/s.

Convenience in placing - unloading seemed relatively comfortable to the lifters. They used both hands to remove the beam from their shoulders, lowered it a bit and held one flange with one hand supporting the beam at the bottom with another hand. The beam was then allowed to land with the open end of the lower flange. It was placed slowly and carefully no to injure the lifters' toes and fingers.

(v)- 1. Flanges Facing Upwards by Hand-lifting Method.

Structural effect - on inspection before and after lifting, transporting and placing of the beam by this method, the beam bore no structural defects. Some minor chippings on the landing edge were noticed.

Safety and convenience: Lifting – a beam was tilted to allow hands to go underneath and then lifted to the lifters' waists. It was not easy for the lifters' hands to grip onto the beam, though it was comparatively easy to pull the beam to their waists.

Loaded movement - moving from one place to another carrying the beam seemed okay, but relatively slow. Lifters reported that most of the weight was supported by fingers, meaning there was no good hand-grip onto the beam.

Convenience in placing - unloading the beam seemed quite difficult. The lifters slid their one hand slowly on the underside of the beam along the bottom flange with another hand gripping around the top corner of the web to allow the beam to land with the bottom edge of the web. Slipping of the beam did not happen but it seemed highly possible. The method and the holding position seemed very uncomfortable to the lifters especially the man in the middle of the beam.

(v)- 2. Flanges Facing Upwards by Shouldering Method

Structural effect - minor chippings were observed on the landing edge of the beam that might have been caused by placing, otherwise no other damages or any other structural effects were noticed.

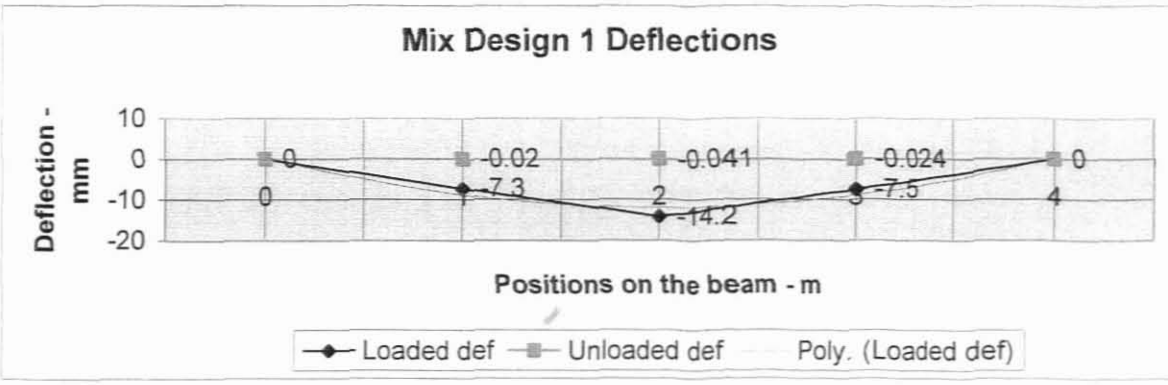
Safety and convenience: Lifting - the beam was tilted to allow lifters' hands to get a good grip. Then the beam was lifted by both hands to the shoulders. Lifting seemed reasonably well to the men at the far ends of the beam while for the one at the middle it cost a bit more effort to change hands around and lift the beam to his shoulder.
Loaded movement - movement happened easily and comfortably with both hands supporting the flanges of the beam.

Convenience in placing - lowering and unloading the beam was not easy, and even more difficult for the middleman. The most difficult part was changing from shoulders to suitable hands' positions to place the beam. Like in the method above, lifters had their one hand holding the bottom flange and the other hand on the top corner of the web. The beam landed on the bottom edge of the web and finally on its bottom plane. This method of placing in general did not seem comfortable to the lifters.

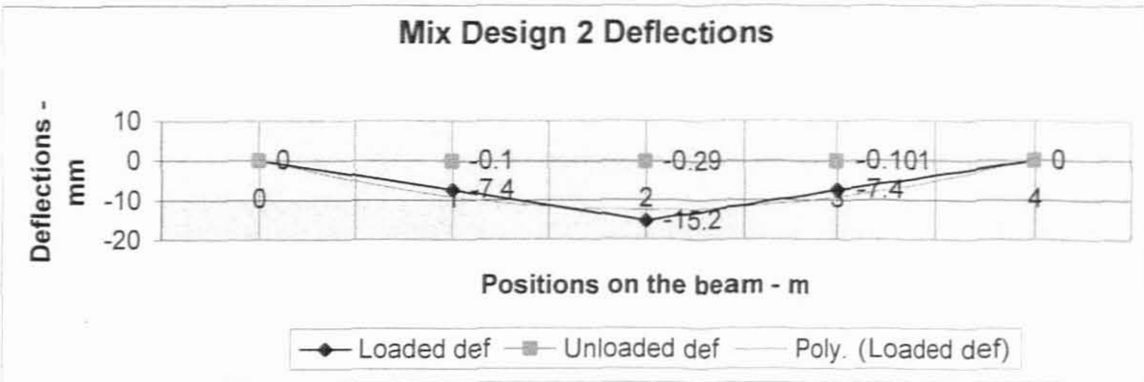
4.6 DEFLECTION

Beams of different mix designs were tested for deflection, and measurements were taken at three places along the beam as mentioned in chapter three (at 1.0 m, 2.0 m and 3.0 m). Beams were inspected before loading, after 24 hours of loading and after unloading. The following table 4.2 below shows the test results of the deflections.

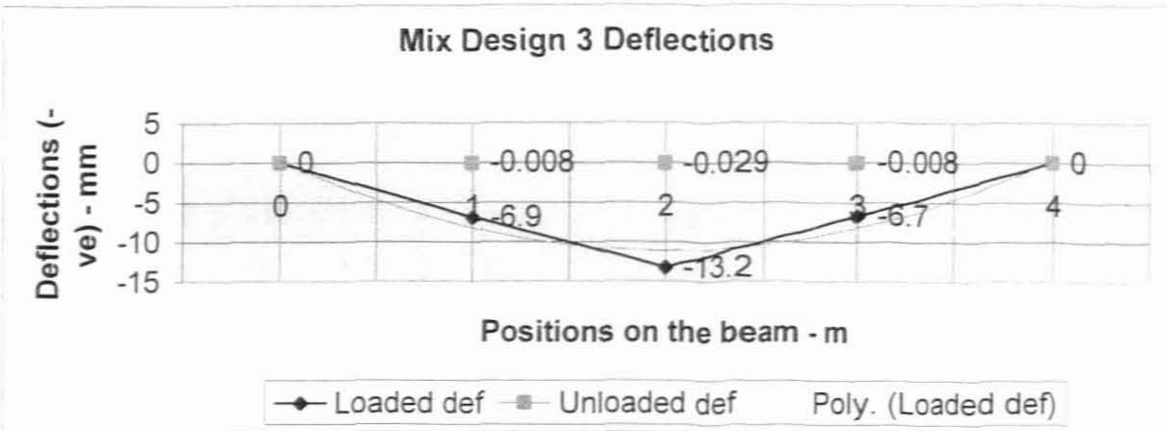
	Inspection Time	**Beam Inspection Position**						
		0.0m-ends	**1.0 m**		**2.0 m**		**3.0 m**	
Mix 1 Beams	Before weights	400	405.0mm		409.7mm		405.0mm	
	After 24 hours	400	397.7mm		395.5mm		397.5mm	
	After unloading	400	403.9mm		408.5mm		403.7mm	
	Deflection	0.0	7.3mm		14.2mm		7.5mm	
	Recovery	N/A	403.9	99.72%	408.5	99.71%	403.7	99.68%
Mix 2 Beams	Before weights	296.0	299.0mm		301.3mm		299.0mm	
	After 24 hours	296.0	291.6mm		286.1mm		291.6mm	
	After unloading	296.0	294.7mm		295.4mm		294.9mm	
	Deflection	0.0	7.4mm		15.2mm		7.4mm	



(a) Deflections and Recovery Graph (Mix 1)



(b) Deflections and Recovery Graph (Mix2)



(c) Deflections and Recovery Graph (Mix 3)

Fig. 4.4 (a), (b) & (c) - Deflections and Recovery graphs

4.6.4 Actual Deflection vs Allowable Deflection

According to SABS0160, deflection of a simply supported beam should not exceed span/250.

Length of beams = 4 000 mm

Allowable deflection = 4 000/250 = 16.00 mm

Actual deflections of beams (mix 1) =14.2mm; (Mix 2)=15.2mm; and (mix3)= 13.7mm.

All actual deflections < allowable deflection.

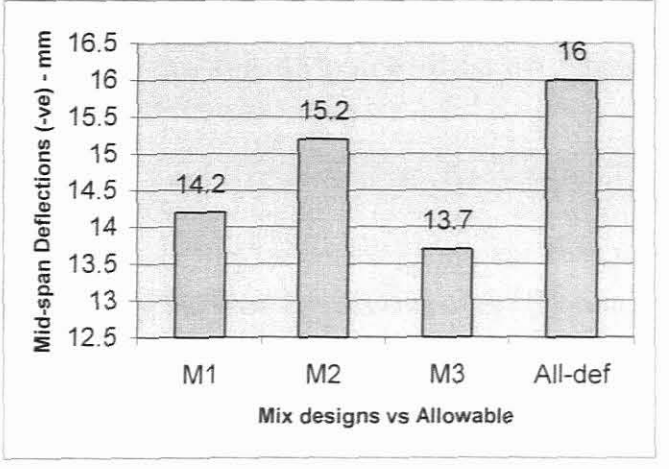


Fig. 4.5 - Actual deflections vs Allowable deflection

Deflections of beams were compared with the allowable deflection of concrete beams of the South African Bureau of Standards 0160. All beams as shown above show results falling within the allowable limits of deflection.

4.6.5 Actual Deflection vs Theoretical Deflection

Correlation of deflection results was made between deflections obtained experimentally and deflections obtained from the theoretical calculations according to the South African standard procedures set out in Appendix 1.

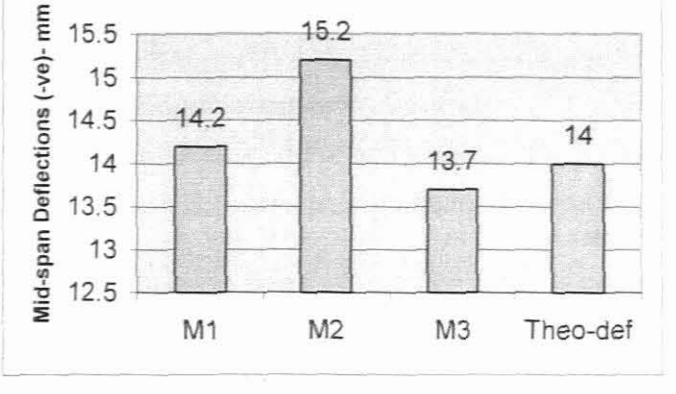


Fig. 4.6 - Actual deflections vs Theoretical deflection

4.7 INTERLOCKING

Some buckling and relatively poor surface finish were noticed on some beams especially the ones that were cast late in the process. The formwork that had been used more than twice caused the problem. These and mainly the skewness of the beams resulted in poor interlocking of beams.

4.7.1 Formwork

Formwork to C-beams was made out of wood. The first few units came out with a satisfactory surface finish, including grooves and projections for interlocking. The rest of the units came out with some defects resulting from the wood: defects like poor surface finish to concrete and improper curvatures. C-beams formed in this type of formwork did not interlock properly; They left holes not patchable with concrete.

4.7.2 Compaction Between Shear Links

Compaction of concrete between shear links along the beams' joints was done properly where there were no holes through . This contributed to the good interlocking of the C-beam slab in general.

4.8 WATERPROOFING

The whole process and tests pertaining to waterproofing was quite laborious. Going through every joint carefully was critical because the failure thereof would render the slab useless. The following stages of the test were observed.

(a) Jointing - After placing beams on the roof, gaps and holes between the beams were checked. Proper placement of shear links in the grooves was also inspected. Where shear links were not properly placed during placing of beams, it became very difficult to place links properly while the whole slab was now in place because the joints are narrow.

(b) Joint Preparation - Before filling, the joint was cleaned and it seemed difficult because of the shear links especially if there is an oil patch, stone or concrete in between. It did not seem so difficult with dust because it was just blown away from one direction to another. The methods that seemed to be successfully working for cleaning inside the joint grooves were blowing air through the joint and cleaning with water.

(c) Mixing, Application and Tooling Sealant

Mixing - the correct proportions in making up the concrete mix for the joints was important and monitored carefully. There were not noticeable problems with mixing.

Application - on observation, trowelling in of mortar in the joints took a relatively long time to be properly compacted in place. Where trowellers were few and mortar was much, the latter dried before application.

Tooling the Sealant - brushing the surfaces on which the sealant was going to be placed was quite easy. Placing of the sealant along the joint did not pose any problems. Some irregularities in thickness were noticed at some points. These might have been caused by inconsistency in pressing in the spray button (trigger) of the sealant bottle.

(d) Base Preparations

The main test on base preparation was the floor's absorptiveness to water. Though the test was done in a very hot day where loss of water by evaporation could be quite significant, the absorptiveness of the base concrete was considered low because after some few minutes (+/- 10) there was some water standing. On portions where some drops of concrete and dirt/dust were not properly removed, absorption was a bit higher than on well cleaned concrete base.

(e) Screeding

The floor was inspected for cleanliness before screeding. Some drops of sealant on unintended surfaces were difficult to remove especially after it had set. Drops of mortar for filling the joints was relatively easy to remove from the concrete surfaces. The inspection was also on the grouted area to be screeded to check whether grout uniformly covered the whole area to be screeded. Grouting posed no problems to the workers. It was done quickly and conveniently by hand brooms.

Application of the screed mortar was done quite carefully to produce the final finish of the slab shedding water in a specified direction with a slope of not less than 3 %. It did not seem to pose difficulties when it was done to levels with a fish-line. Compaction of screed mortar was done by straight-edges to the discretion of the worker, but the general requirement was that the mortar will show a sign of compaction when it becomes more wet at the top (fines show at the top of the mortar). Smoothing of the layer by cement paste was done better by steel floating trowels than by building trowels.

(f) Curing

Sand that was used for curing was easily blown away by strong winds, especially along the edges of the slab. The slab also comparatively easily lost moisture as a result of wind at the edges. The sand also got washed away by running water at the draining end of the slab. Otherwise the slab remained wet for the whole curing period (7 days).

(g) Damming

It was quite some effort to remove the curing sand to prepare for the next test. It also became dusty where removal was not done with care. Clay material that was placed along the edges of the slab to retain water on the slab was generally effective. Ten pieces of paper were cut and labelled. The paper pieces were then mixed together and picked one-by-one to be placed on the floor soffit. Positioning of the pieces on the soffit was done at any point on the joints with no selection.

The following is the waterproofing test results done on the slab and the layout of the randomly placed testing papers on the soffit joints.

Leakage Inspection Report							Reporter: K. Chalatse Date: 15-October-2001
Paper No.	Paper Condition at Time of inspection (Hour)						
	0^{th}	8th	14th	19th	22nd	24th	Notes
1	dry	dry	dry	dry	dry	dry	ok
2	dry	dry	dry	dry	dry	dry	ok
3	dry	dry	dry	dry	dry	dry	ok
4	dry	dry	dry	dry	dry	dry	ok
5	dry	dry	dry	soft	damp change paper	soft	moisture comes out slowly
6	dry	dry	dry	dry	dry	dry	ok
7	dry	dry	dry	dry	dry	dry	ok
8	dry	dry	dry	soft	damp change paper	damp	moisture comes out constantly after 22nd hour
9	dry	dry	dry	soft	soft	soft	moisture is very low and shows no change
10	dry	dry	dry	dry	dry	dry	ok

Table 4.3 - moisture inspection

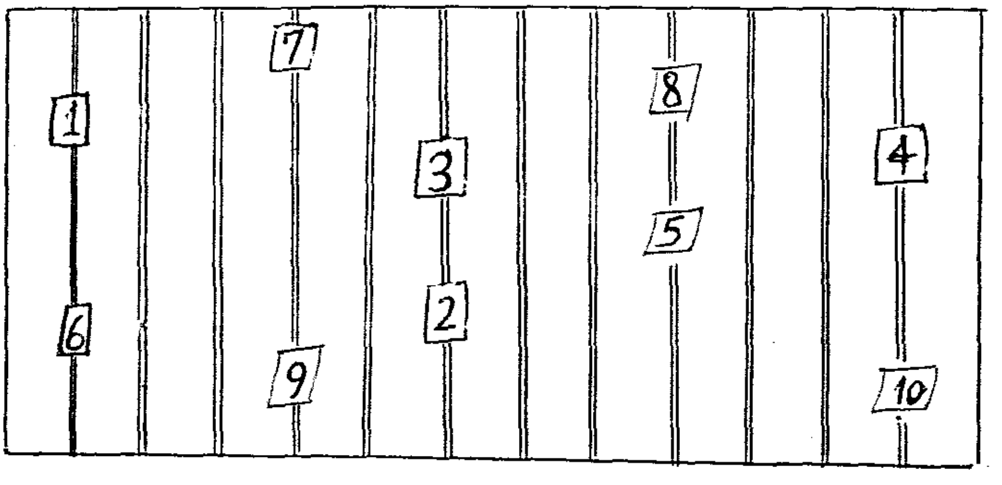


Fig. 4.7 - layout of the randomly placed testing papers on the soffit joints.

(h) Sealing the Soffit Joints

After 24 hours of sealing the joints, it was noticed that at positions where C-beams had not perfectly touched face-to-face, the sealant was visible and protruding. This happened as the sealant expanded. It was cut to flush with the soffit of the slab.

(i) Damming After Sealing Soffit Joints

The following are the waterproofing results done on the slab and the layout of papers on the slab soffit after sealing the soffit joints.

Leakage Inspection Report							Reporter: K. Chalatse & C. McClinton
							Date: 20th - October - 2001
Paper No.	Time of inspection						
	0th	8th	14th	19th	22nd	24th	Notes
1	dry	dry	dry	dry	dry	dry	ok
2	dry	dry	dry	dry	dry	dry	ok
3	dry	dry	dry	dry	dry	dry	ok
4	dry	dry	dry	dry	dry	dry	ok
5	dry	dry	dry	dry	dry	dry	ok
6	dry	dry	dry	dry	dry	dry	ok
7	dry	dry	dry	dry	dry	dry	ok
8	dry	dry	dry	dry	dry	dry	ok - but may accumulate water within the beam
9	dry	dry	dry	dry	dry	dry	ok
10	dry	dry	dry	dry	dry	dry	ok

Table 4.4 - moisture inspection after soffit sealing

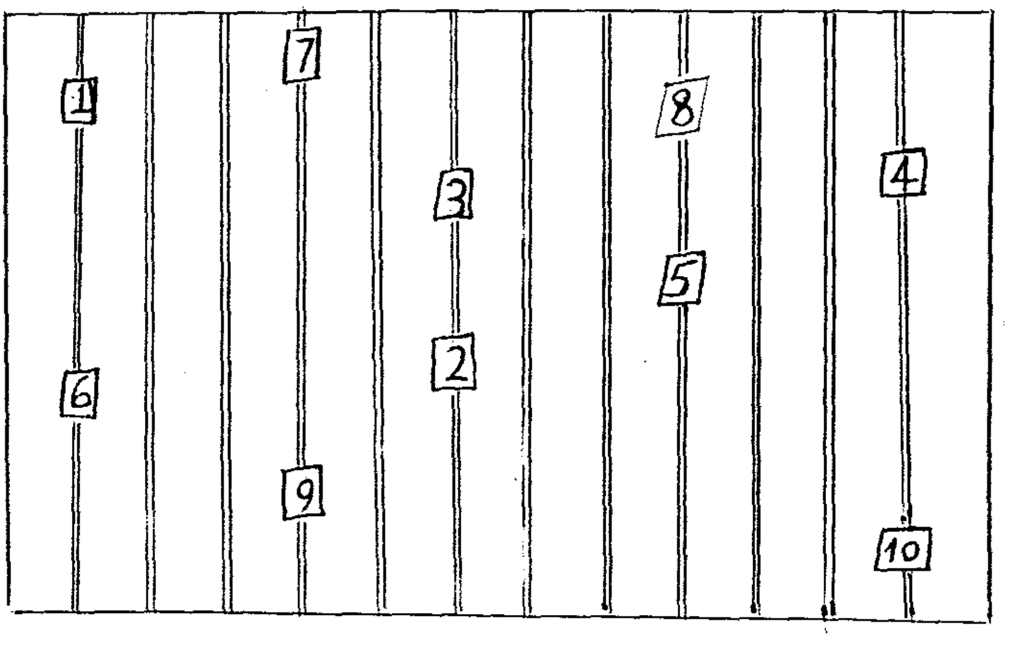


Fig 4.8 - layout of papers on the slab soffit after sealing the soffit joints.

4.9 ANALYSIS OF C-BEAM ENVIRONMENTAL FLAT ROOF SURVEY DATA

A survey was done on urban areas around Cape Town, South Africa and Maseru, Lesotho. The objective of the exercise was to determine movements of people from their original homes to cities for job seeking and results thereof.

ITEM		% POS.	% NEG.	COMMENTS
Movements:	from rural areas	75	25	According to the survey done, 75% of urban residents moved in from their rural areas.
	job seeking	71	29	Of the sample taken on the survey, 71% moved to urban areas basically seeking for jobs.
Accommodation:	difficult to get a site	56	44	For a fairly good percentage (44%) of urban residents, accommodation is not too expensive because municipalities subsidise. While for 56% it is expensive in terms of buying a house or building one.
	small plots	93	7	Municipalities provides small plots ranging from 100 m2 to 400 m2. 93% of the residents are allocated plots of 100 m2 to 200 m2, while 7% has bigger plots of up to 400 m2.
	formal house	44	56	Generally all urban houses were informal at their original state and then developed to formal houses. At the time of survey 56% of the houses were informal and not developed yet.
Gardening:	small garden	96	4	A formal house basically occupies the whole space on plots of 100 m2 to 200 m2. Therefore, there is hardly any space for gardening. 74% of the residents are not happy with the amount of space available for gardening and other family activities.
	no space for activities	74	26	
Flat Roof:	garden extension	94	6	Feedback from urban residents about greened concrete flat roofing is positive (94%). They consider it as a way of garden extension and also as an expended space for other activities eg. recreation, swimming pool, etc.
	security	93	7	93% believe that the roofing will bestow more security than the conventional pitched sheet roofing. It will provide security against blowing winds, against fire, enhance sound proofing and security against robbers.
Job Creation	difficult to get a job	90	10	Most of the residents moved into urban areas seeking for jobs. 90% of these people say getting a job is difficult, depending on the level of education, work experience, type of profession, etc. The competition is very high.
	job creation by roof garden	90	10	90% of the sample taken believes that a roof garden can be a good opportunity for job creation, as many people are without jobs now.
	benefit to the country	96	4	96% believe their country could benefit an improved economy: more people working and earning money, reduced crime as people would be occupied by work to do, reduced importation of vegetables, and through tourism.

Environment	difference in environment from rural areas to urban areas	98	2	98% of the residents are aware of the difference in environment from their rural areas to urban areas where there is less greenery, most of the ground is paved, dumping of garbage on open grounds, and with air polluted by factories and cars. They believe greening rooftops will significantly improve the environment around, not only by improving the freshness of the air, but by also enhancing the beauty of their villages.

4.10 ROOF GARDEN'S FEEDBACK

Introduction

A group of ladies at Cape Technikon walked up the stairs to the rooftop of grass roofed lectures halls of Cape Technikon. They walked around the rooftop, watered the plants, cultivated the grass on the rooftop and also relaxed thereon. Thereafter they were interviewed on the exercise. The objective of the whole exercise was to test the concept of having activities on the C-Beam rooftop. The following is the summary of the feedback.

Walking to and on the rooftop

Walking to the rooftop is okay especially with the security of handrails at the edge of the staircase. It is like walking from one floor to another in a normal floor to floor up stairs walking situation.

Walking on the rooftop does not scare especially at one or more meters away from the edges into the roof centre. In fact it feels more relaxing sitting at the top on the greenery and in fresher air.

Handrails along the edges of the rooftop are recommended because some people are afraid of heights, and mainly for safety.

Watering

Taking water to the rooftop by a bucket is a tiring job. Watering the whole roof of plant-pots requires many trips of buckets of water. This may be too laborious. As for old people, this method of watering will simply not work. The method recommended would be to deliver water by pressure hosepipe. A bucket or sprinkler can be used at the top for watering the plants.

Many people like the concept of greened rooftop as also reflected in 4.9. Even though unpresurised water taps like tank water and ground water 'taps' may have some constraints as far as roof plants watering is concerned, there are many other benefits in the whole system. Therefore even people under such conditions are encouraged to buy the idea.

Most water systems in urban residential areas are pressure taps in which case the concept can work easier.

Growing Plants

All garden vegetables and plants can grow on the rooftop. Height does not influence growth here. for example, vegetables and garden-plants do grow on the naturally more elevated terrains than the rooftop. All that is required is the necessary depth of soil for vegetables. Most vegetable gardens and flowers can grow well in a 150mm high and 200mm diameter plant pot.

Viewing From the rooftop
Sitting and relaxing with friends on a green rooftop is really wonderful. Fresh and cool breeze on the rooftop refreshes, and it is good for health.

It is a good experience to be at the top, watching people passing by. 'The higher one is above people, the more superior one feels towards the lower' say the respondents. It gives one a good view of villages and people and neighbours walking around, which is loved by most women.

Culture
Staying on the rooftop has no cultural implications or constraints. It is actually an advantage to some African women for drying fruits, green vegetable leaves for later use, cereal grains, etc. These activities are still done on rooftops with a help of ladders for those who have them or other unsafe means of getting to the rooftop like drums.

4.11 CONCLUSIONS

Different mixes were designed under the same conditions for mixing, casting, curing and loading. The difference was only in proportioning of the mix components. Mix 3 produced the highest quality C-Beam of the three mix designs, then mix and lastly mix 2. Good structural qualities of mix 3 is associated with the grading of aggregates (well graded) and also the ratio of cement to aggregates and water.

Concrete mix 3 produced concrete units with minimum structural defects like cracking, surface finish and deflection. Compared to mix 1 and 2, mix 3 had the lowest deflection and the highest recovery as shown in Table 4.2 and Figure 4.4. Though all mixes pass the Allowable deflection by SABS, mix 3 is the safest of the three mixes (Figure 4.5).

Two methods of handling C-Beams were used and several holding positions were tried. The position that suited the lifters was holding the beam as it would sit in its operating situation. The two methods (shouldering and hand lifting) suited the position well.

A group of ladies was taken to the Cape Technikon's roof garden to test the concept of the C-Beam environmental Roof garden. They did activities like walking up the stairs, watering plants and relaxing on the rooftop. Their response was positive towards the concept (4.9).

CHAPTER 5

FORMULATION AND DISCUSSION OF SOLUTIONS

5.1 FORMWORK

The formwork that was used in the construction of C-beam was wooden. On observation the wooden boards were used a few times as formwork before they got damaged as a result of nailing pieces together and unnailing them during stripping. A repeated gluing and ungluing of the boards also render the formwork leaking. Wooden boards used repeatedly loose the required final surface finish to the C-beams especially on the soffit side where it is intended to act as a ceiling (final finish). All these require wooden boards for formwork to be changed often to meet the required standard to the surface finish of the C-beam.

For large-scale production of C-beams, steel formwork could be a lot more cost effective compared to the wooden formwork. One can be sure of uniform and desirable final surface finish to slab soffits acting as ceilings to the lower rooms. This type of formwork though expensive compared to the wooden one, lasts much longer and in the long run it becomes cost effective.

5.2 PRESTRESSED TENDONS

Prestressing the tendons determines the structural capacity of the C-beam, therefore prestressing should be done with maximum care to give uniform camber to the units and well-aligned joints. This becomes an issue now that tendons have to be stressed deferentially. The importance of this is seen when it comes to C-beams interlocking. It further affects the waterproofing of the slab as a whole. It is therefore recommended that C-Beams construction be done by an independent company or by the Municipality to ascertain compliance with standards and specifications. Then people will buy the beams from the manufacturer.

5.3 CONCRETE MIX AND STRENGTH

5.3.1 Mix Proportions and Strength

Concrete is a mixture of cement and aggregates from fine to large aggregates. Properties and combinations of the components of concrete influence the concrete strength. An influence on the three mix designs of the C-beam was largely as a result of combination of components because properties were similar in all mixes.

(a) Mix 1

(i) Influence of aggregates - this mix is suspected to be a bit on the fine side lacking some strength.

(ii) Influence of cement - the cement content may have improved the strength of the mix.

(b) Mix 2

(i) Influence of aggregates - there could be an influence of much stone to crusher dust. It is suspected that it could be a little bit too course lacking fines.

(ii) Influence of cement - the cement content on the other side could comparatively be on the low side resulting in lower strength.

(c) Mix 3

(i) Influence of aggregates - this could be well-graded mix, balanced from fines to course aggregates in relatively good proportions. This may have contributed not only to the strength but to the final surface finish of the product as well.

(ii) Influence of cement - in comparison to mix 1, mix 3 has high cement content and this is believed to have contributed to the strength of the mix.

The graph below shows cube strength of the mixes crushed at 7days, 14 days, 21 days and 28 days.

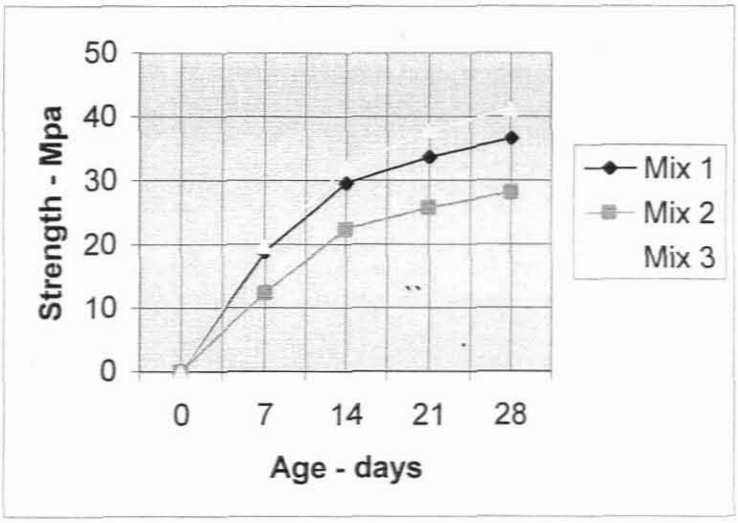


Fig 5.1 Concrete cube strength

5.3.2 Electricity aided Compaction

Concrete strength is also influenced by its compaction. Compaction of C-beams and cube moulds was done by hand. This method is not only time-consuming but may also result in un-uniform compaction of concrete in the moulds. Making use of electric vibrating machines and tables could attain a good-looking product whose concrete strength is also improved. These, though expensive may eventually be cost effective on large-scale production and where time plays an important role.

5.4 STRIPPING AND CURING OF C-BEAMS

5.4.1 Stripping of Formwork

Wooden formwork is normally bound together by glue and/or nails. When the same boards are used repeatedly for formwork, the nailwork and gluing make it difficult to strip the formwork and in most cases damage the boards. It also happened that the concrete units get damaged in the process because they are still fragile at the stage. Proper and uniform oiling of the boards facilitates stripping while conversely loss of water from concrete to wooden boards occurs and affects strength and quality of concrete.

5.4.2 Curing of C-beams

Curing of C-beams was done with wetted sag-clothes. This system worked fairly well but some defects were noticed. On some beams the 170mm side had narrow cracks. They were identified as shrinkage cracks resulting from loss of moisture from concrete by heat.

Curing by wetted sag-clothing may even be more inaccurately done on large-scale production, and this can then cause a considerable deterioration in the performance of the C-beam structurally. The use of once-applied curing compound on freshly stripped concrete faces can do a lot better curing on the concrete units.

5.5 HANDLING

Beams were transported from one place to another and from the ground to the roof using two lifting methods at four lifting positions.

5.5.1 Lifting Methods

(a) Shouldering Method - As it had been shown in the previous chapter, a considerable amount of time is taken on lifting the beam to the shoulder and also on placing the beam to the ground. On the other hand when the beam is on shoulders movement can be very quick.

(b) Hand-lifting Method - Contrarily, it takes relatively shorter time to lift and to place beams, and comparatively longer time on movement from one place to another.

Both lifting methods are acceptable and could be used interchangeably by the lifters depending on their convenience at the point in time.

5.5.2 Lifting Positions

Beams were lifted held at different positions to determine the best holding and lifting position. The following are the positions and discussion thereon.

(a) C-beams Roofing Position

The roofing position of the C-beam may have not come out as the very best in terms of convenience of lifting, movement and placing, but it was generally convenient, comfortable, safe and therefore acceptable. Because beams are lifted and placed in the same way as they would sit for all their lives, there is no fear of structural damage or injury to the beams except in the case of an accident. The reason for this is that stresses are expected to be induced at places on the beam where they are catered for and can do no harm to the beam. This lifting position is therefore recommended.

(b) Flange Position

This is where the beam is held and lifted with the whole of its body suspended from the flanges. The initial lifting of the beam seemed comfortable and easy but does not last long because it is done basically by one hand while the other supports. Because of the weight of the beam, it is dangerous to hold the beam by one hand. If a tired hand loses grip people could be badly injured by the beam.

Some beams developed cracks because of this lifting position. It is as a result of inducing too much stresses at places that are not designed for that amount of stresses.

This position, on the basis of the reasons above is therefore not recommended.

(c) Flanges Facing Down Position

The lifters grip with one hand on one flange and the other on the other flange. To the lifters, this position is very comfortable and convenient, but it is not the best structurally. At the time of lifting and transportation, tensile stresses are induced at sections where that amount of tension is not designed for. It may even be worse at the time of shocks resulting from false movement from lifters, etc. Therefore the position is not recommended.

(d) Flanges Facing Up Position

This position has shown to be convenient to the lifters when using shouldering method than hand lifting method because of the flanges. The other reason is that the third lifter in the middle can also use the shoulder method. This position like others mentioned above may be comfortable when lifting from the ground, it may be convenient during movement and comfortable at placing, but structurally it may cause some injury or damage to the C-beam itself by inducing stresses at positions that are not designed for them. This may happen during lifting, transportation or placing. It may happen during rash time or at the time of false movement by any one of the lifters (this often happens during rash hour). During lifting and placing beams may experience shock.

This lifting position on the C-beam is therefore not recommended.

5.6 DEFLECTION

The test results on deflection of C-beams show different degrees of deflections. Everything was common for all C-beams except for the components of mixes. The quality of components, workmanship, prestressing, curing, loading etc. was the same for all beams. It is therefore evident that proportions of components of mixes have an influence on the strength of the beam against deflection.

5.6.1 Mix 1 Components

Cement CEM II 42.5 = 450 kg/m^3

Water - clean = 230 l/m^3

Stone - dolerite 6.7 to 9.5mm = 1100 kg/m^3

River sand = 680 kg/m^3

Crusher dust = 0.0 kg/m^3

The actual average deflection of beams of this mix was 14.2 mm. Compared to the Allowable Deflection by SABS 0160 of 16.0 mm, the deflection is acceptable. It is however a little higher than the theoretical deflection (14.0 mm). A little gap in the grading size from fine to large aggregates may have contributed to the low deflections and compressive strength.

5.6.2 Mix 2 Components

Cement - CEM II 42.5 = 404 kg/m^3

Water - clean = 170.5 l/m^3

Stone - dolerite 6.7 to 9.5 mm = 1150 kg/m^3

River sand = 0.0 kg/m^3

Crusher dust = 860 kg/m^3

The actual average deflection of beams of this mix was 15.2 mm. Though it is lower than the Allowable Deflection by SABS 0160 (16.0 mm), it is a lot higher than the Theoretical Deflection. The great influence is associated with shortage of fines in the mix and the low water to cement ratio. Fines have a better influence on concrete structures in tension than big aggregates. In general the mix was the lowest of the three mixes in compression as shown in figure 5.1above. The mix is therefore not recommended.

5.6.3 Mix 3 Components

Cement - CEM II 42.5 = 452 kg/m^3

Water - clean = 235 l/m^3

Stone - dolerite 6.7 to 9.5 mm = 715 kg/m^3

River sand = 645 kg/m^3

Crusher dust = 325 kg/m^3

The actual average deflection of the beams of this mix was 13.7 mm. The degree of deflection came out lower than both the Allowable (16.0 mm) and the Theoretical (14.0mm). The compressive strength (fig. 4.1), the deflections (table 4.2) and the recovery of beams (fig. 4.3a-c) have shown this mix to be the strongest of the three mixes. Because everything else is similar for all concrete materials, it is therefore concluded that the proportioning of materials in this mix is the one that produced good results.

Mix design 3 is recommended among the mix designs because tests have proven it the best. It is also assumed that beams of mix design 3 interlocked and joined together properly in a slab will result in a lot less deflection because then the load will be shared and distributed over the other beams of the slab when they work together as a unit slab.

Fig 5.2 below shows deflections on different tests of the C-beam.

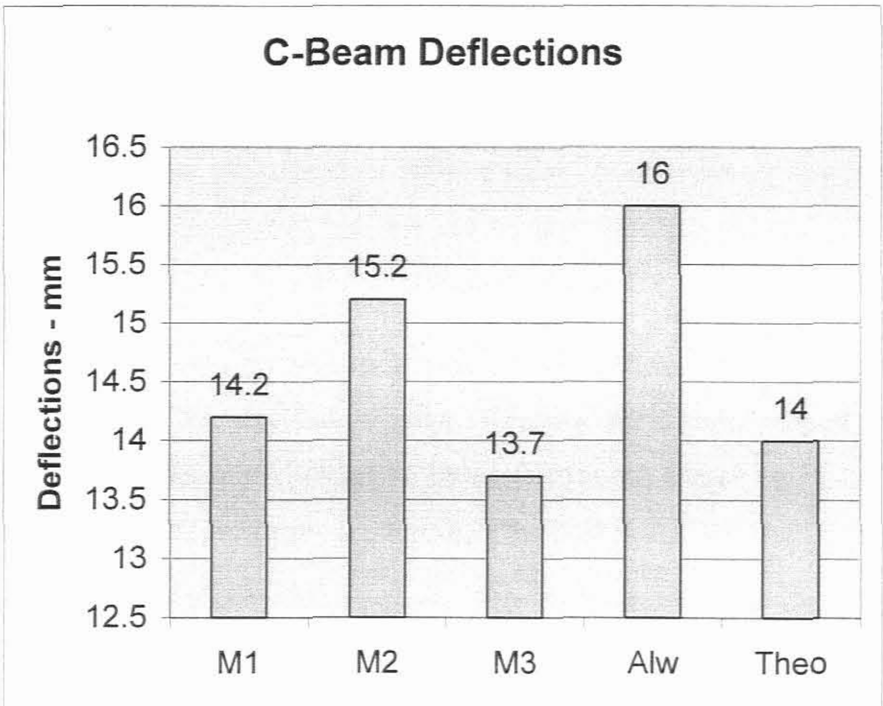


Fig. 5.2 Actual deflections, allowable and theoretical deflections

5.7 INTERLOCKING

The ability of beams to grip and get attached to one another depends on many factors, e.g. formwork, positioning of the beams after stripping, curing and damages to the interlocking beam projections. All or most of the factors mentioned above were experienced during the testing process of the C-beam. Beams that were badly affected by these factors were not used on the testing of the C-beam units for the roof slab.

5.7.1 Formwork

A few beams came out right with desired surface finish and grooves and projections from one wooden formwork, while the rest were not so good because the formwork was now bad. The reason for this is gluing and dismantling, nailing and pulling-off of nails from the formwork. It easily got damaged. From this experience, it is recommended that steel boards be used for mass production of C-beams. This formwork system will be a lot economical.

5.7.2 Positioning After Stripping

Beams that were not seated in their loaded sitting position or seated in a tilted position after stripping were later found to be skew and not interlocking with the other beams properly. It is therefore recommended that beams be cured on a solid and flat curing platform, and seated in their functioning position.

5.7.3 Curing

Beams that were not wetted properly tent to deflect and form shrinkage cracks in the direction of the highest loss of moisture. This resulted in skew C-beams, not fitting properly with others during interlocking. Curing of beams should therefore be uniform to all beams under the process. A curing compound is recommended for uniformity in curing of the beams.

5.7.4 Damage to Interlocking Projections

This happens at any stage of the beam between stripping and jointing. The projections on the C-beam are quite thin and need to be worked carefully so as not to damage them.

5.7.5 Shear Links

If shear links are not properly placed just before interlocking a beam to the next one, they can be a serious hindrance to interlocking and hence poor waterproofing and finally the malfunctioning of the roof-slab.

Properly interlocked C-beams effect the most important elements in the life and suitability of the C-beam to the house owner. The most important elements that are effected by good interlocking beams are waterproofing and an improved structural sustainability of beams working together in uniform distribution of loads applied at the top of the slab, reduced beam deflection, etc.

5.8 WATERPROOFING

Functionality and life of the C-beam roof-slab depends directly on its ability to prevent water leakage through to the soffits of the slab. Adequate compaction to C-beams will reduce its absorptiveness to water, proper sealing of the joints will also play an important role in preventing water from leaking through to the soffits, hence a functional slab as far as waterproofing is concerned.

The following subjects will be discussed: jointing; joint preparation; mixing, application and tooling sealant; base preparation; screeding; curing, damming and sealing the soffit joints; and damming after sealing soffit joints.

5.8.1 Jointing

From the test, it is proved that the projecting shear links can be a serious hindrance to proper jointing if not properly placed before the process to fit in the grooves nicely. If they are pointed down or up, they can be a pathway of moisture into the slab. Mortar and sealant may not be able to seal properly around the wires. It makes it difficult to compact mortar if wires are not pointing horizontally into the grooves. Shear links need to be bent as shown in figure 3.8 to help with the lateral stability of the slab.

To avoid all the above-mentioned problems and achieve the expected maximum performance of the slab, shear links should be aligned and bent properly while the beam is on the ground or just before it is interlocked with the other beams on the slab.

5.8.2 Joint Preparation

Joints of the C-beam roof-slab do easily collect dust when beams are laid interlocking one to the next before filling the joints. Dust is easy to remove from the joints by blowing with compressed air, compressed or running water. An experience with a small stone fallen in the joint between the shear links showed that it may be difficult to remove it with air or water, while sealing it inside may cause leakage problems.

One or both options of cleaning the joints (air and water) are recommended, but if water is used allowance should be made before sealing the soffit joints so that the water between the top and soffit joints is dried up. It is also advisable that stones or objects that cannot be washed or blown away should be kept away from the joints. Soap and cloth could be used to wash away oily dirt, then rinsed with clean water.

5.8.3 Mixing - Application - Tooling Sealant

Mixing of mortar for the C-beam joints needs to be carefully and thoroughly done. Hand-mixing is as well acceptable for jointing mortar. Application of mortar into the C-beam needs concentration and carefulness from the workers. The reason for this is the narrowness of the joint they need to work the mortar through, the need for the mortar to go around and beneath the shear links in the joint, and the need for the joint mortar to be properly compacted. It is therefore recommended that hand trowels be used to place and to compact the mortar. Compaction can be done by tamping and pushing mortar through the joint to the bottom, and into the joint grooves by the edge of the trowel. It is also important to make enough batches of mortar to avoid setting and hardening of mortar before application. This will be in the discretion of the builder depending on the skill and the amount of his labourforce.

Different sealants have different application system and instructions from their manufacturers. It is highly recommended that manufacturers instructions be adhered to for application of the sealant. Brushing and thorough cleaning of the surfaces on which the sealant is going to be applied is of paramount importance. A sealant needs to sit directly on the base concrete with which it should form a watertight joint. With polyurethane it is easy to press the trigger then run it down the length of the joint and to the height just above the top of the joint. The worker must make sure that the joint is fully sealed with at least 5 mm overlap on both sides of the joint. This is done to make sure that the joint is watertight. The product is expected to expand further into some voids that could not be filled during the sealant application. If this is done properly, the joint should be watertight.

5.8.4 Base Preparations.

It was found out from the tests that the absorptiveness of abase concrete is directly related to the concrete's integrity. It is therefore recommended that mix designs be adhered to - the quality of compaction of beams be maintained high and also the curing of the concrete be done properly. The concrete base should then be well cleaned before screeding. Concrete or mortar droplets should be scraped, dust swept and washed away, oil be cleaned with soap and rinsed with clean water.

5.8.5 Screeding

It is recommended that screeding should be done in a perpendicular direction to the joints of the C-beam so that the directions of C-beam joints would not coincide with the screed joints. Screeding should follow grouting closely lest grouting dries up before covered with screed. Enough batches of grout are therefore recommended depending on the labourforce and their skill.

Because compaction is done by hand, it is important that workers take their time compacting the screed to get a good density.

Cutting the screed to final finished levels given required slope to the surface to shed water, needs careful workmanship because water should not stand on the roof-slab. Use of fishlines, dumpy levels and cutting edges could be done while the screed is still workable. Finishing and smoothing of the surface with cement powder should be worked nicely to give a polished non-absorptive surface texture.

5.8.6 Curing

For high level of performance and durability, screed needs to be cured properly. Some disadvantages were observed on the method of curing used. It is labour-intensive - transportation, laying and removal of sand, and edges may not be as cured as the other parts of the screed because the sand gets blown or washed away. The latter may not be very significant. Otherwise the method works well and gives good results. The other option that could be measured against the method used, is an application of curing compound. This method is less labour-intensive than the former. It could be used where sand application becomes more expensive. It is therefore in the discretion of the user in time to decide which method they find suitable. If curing compound is preferred, the user should follow the manufacturers instructions to get maximum performance from the roof-slab.

5.8.7 Damming

The method used for testing the watertightness of the slab was by means of clay wall at the edges of the slab to retain water on the roof-slab. It involves some labour to put up the retaining wall along the roof-slab edges. The other option could be to open running water on the rooftop for 24 hours, and this means a lot of water will be used. The former is still preferred over the latter method because of the general awareness of water conservation by the department of water affairs. It is in the discretion of the user to choose the method they want.

5.8.8 Sealing Soffit Joints and Second Damming

Tests have shown that it is almost impossible to shoot a sealant from one joint end to at least 2.0 m distance, with shear links all along the joint to hinder the shot product, unless stronger pumps are used. It is therefore very imperative to properly interlock the beams, carefully seal the joints and nicely work the screed to minimise chances of leakage from the top of the flange.

Polyurethane expands and protrudes through open joints to the soffit of the slab. This is not aesthetically favourable if the slab soffit is intended to be the ceiling of the room. The projections could be cut but it is more advisable to use undamaged beams and to do the interlocking properly before the sealant application. The water tightness test rests generally showed a well-waterproofed slab.

5.9 CONCLUSIONS

The South African pine boards that were used for formwork seemed to work fine twice or thrice for the same boards but tend to loose acceptable surface texture and don't join properly because of repeated stripping and joining of boards with nails and glue. It is therefore advicable for the everyday C-Beam producer to use steel formwork.

Concrete mix 3 produced units of relatively high properties. The cube crushing strength was 41.2 Mpa at 28 days which complies with the design strength required (Fig 5.1); the deflection of the concrete units are smaller than the theoretical and allowable deflections required by SABS 0100-01-1992, thereby meeting the requirements (Fig 5.32). The units thereof also have the best interlocking properties to all other mixes.

The properties above are attributed to the grading of aggregates (well graded) and proportioning of the mix components as shown in Table 3.1.

Various handling methods and holding positions on the C-Beam were tried, but only two methods and one holding position were found suitable. The two handling methods are shouldering and hand-lifting methods; and the holding position is the operating bottom part of the beam as shown in Fig. 27 of the C-Beam Environmental Roof Construction Manual.

Waterproofing of the roof slab constituted a series of operations, everyone of which plays and important role towards the watertightness of the slab:

A proper jointing, good joint preparation of the beam units and the none-buckled units facilitate good waterproofing of the slab.

Proper mixing, application and tooling of the sealant as per manufacturer's instructions is important.

The screed should be proportioned, mixed, applied and cured as per specifications to facilitate good waterproofing.

Top and soffit joints were sealed and tested for watertightness by damming the slab for 24 hours, and the results were positive as shown in Table 4.3.

The C-Beam roof slab construction was done as close a possible to the theoretical design and specification and the functionality of the beams and the roof met the design.

CHAPTER 6

EVALUATING THE CONCEPT

Introduction

This chapter is about evaluating the C-beam in the light of external and internal perceptions to see how it will compete with existing systems by considering its internal and external strengths, opportunities it can stand or provide to the community and the country as a whole, as well as its weaknesses and threats. This is known as a SWOT analysis. (Koontz & Weihrich, 1985)

6.1 STRENGTHS

6.1.1 Job Creation

The strength of the C-beam environmental roofing system lies in its ability to provide jobs for South Africans. Amount of work will vary from house to house depending on the condition of each house. A job concerning the C-bean may include:

(a) Construction: Unroofing – taking down existing roofing for C-beam environmental roofing.

Wall preparation - replacing damaged bricks in walls and preparation for C-beams.

Propping – setting up a support fcr a new roof.

Lifting of C-beams to the rooftop.

Placing of C-beams in position.

Jointing – knitting C-beam units to act together as a roof.

Screeding – roof surface finishing and drainage.

Railing the roof edges – protection against falling from rooftop

(b) Greening the Rooftop:

Greening – plant-pots with soil will be transported to the top of the roof and planting will then follow.

Taking care of plants – plants will need to be taken care of in many ways; be it vegetables or any another plants suitable for the depth of soil. Watering, cultivating, fertilizing, etc. will be needed continually. The Cape Technikon's grass roofed lecture halls below (Fig. 6.1) shows the beauty of a roof garden that is well taken care of .

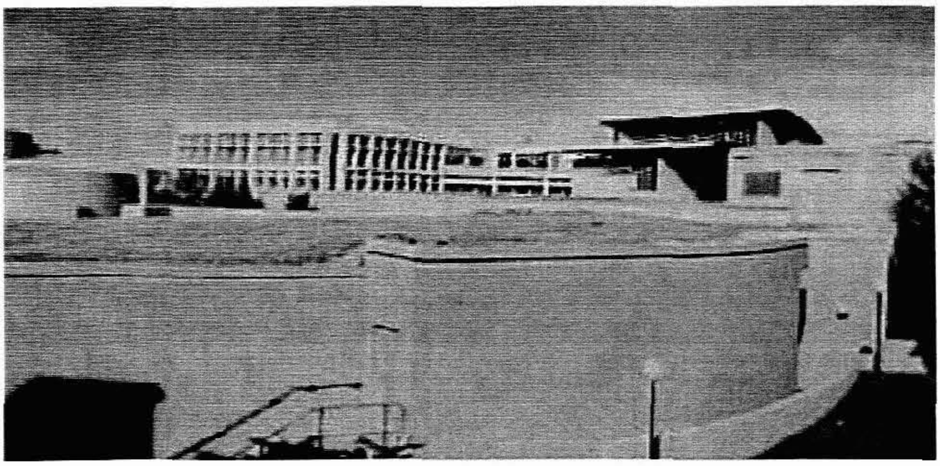


Fig. 6.1 Cape Technikon's Roof Garden

Even though the construction part of the job will come to an end at some point, the rest of the work like greening the rooftop and taking care of plants is continuous. It therefore remains an all-time job for the owner. Effectively not every house owner will work on his house otherwise other jobs may have to stop while the C-beam roof is being constructed. This means job for the jobless - the house owner who is currently without a job can do it for those working. Eventually there will be an added number of people working in total.

6.1.2 Aesthetics

In general, aesthetic qualities of a roof are almost never considered to be of much importance in the design of a roof. This is partially because most people look at roofs from the ground level and also because most roofs are inaccessible. More attention is instead paid to other qualities like shading the occupants from the elements.

A roof is considered to be serving its purpose as long as it does not leak and provides shelter from the elements. This has led to the roofs on our homes being the least attractive part of the building because the roof can only be seen from above, and therefore does not concern the occupants

Naturally people like greenery; not only because of its air freshening and other characteristics, but also just because it looks beautiful. This is why even somebody who does not know the science behind it knows from what their eyes tell them that it is beautiful. This is reflected by the community's perception in chapter 4. Therefore beauty is the strength of the C-beam environmental roof. Most people like relaxing by the greenery like ladies sitting on the roof garden at Cape Technikon (Fig.6.2)

Fig 6.2 Relaxing by the greenery on cape Technikon's Roof Garden

6.1.3 Water Run-off Reduction

Water is a precious resource and can no longer be regarded as a free commodity. Climatic conditions and seasonal changes largely dictate the amount of water available to a community. The world's climatic and seasonal conditions are becoming more erratic.

The total amount of water used in the world has quadrupled during the last fifty years. The increase in the amount of water consumed is due to the increasing population. Some say that the increase in the amount of water consumed is due to progress made over the last decade. How can we call this progress when we are abusing one of the world's most precious resources? (Grozeva, 1994)

The trend over recent decades has been a migration from the rural to urban areas. This has caused serious changes in the natural water cycle as mentioned above. Urban areas have a great deal of their surface area covered with impenetrable surfaces such as roads, concrete areas, parking lots, buildings and their roofs etc. These surfaces all contribute to the high run-off. A typical tiled roof obviously produces a one hundred per cent run-off during precipitation.

Extensive research has taken place on how to reduce the amount of run-off from an urban area by using grassed roofs. As much as fifty per cent run-off reduction was assured by means of the grass roofs (Smith 1997). Plants pots with equal depth of soil to that of a grass roof will be able to reduce fifty per cent of run-off.

Greening of roofs can have a major advantage in that it can reduce the initial peak out flow of a storm in an urban area. One square metre of green roof has a water saturation time varying between few minutes to several hours. It absorbs and prevent stormwater from entering the system as soon as it would in the absence of the roof greenery. This is obviously dependent on the thickness of the soil and the type of greened roof layer and the intensity of the storm.

The delay in stormwater run-off reduces the overall cost of the stormwater installed in a community. The delayed stormwater run-off allows for smaller diameter pipes in the drainage system. Without such delay, pipe sizes of greater diameter would need to be installed to cope with the immediate peak volume of stormwater run-off. The use of over-designed pipes is highly inefficient because a pipe only flows at its full potential for a relatively small part of its design life. By reducing this initial peak, stormwater drainage systems can become more viable.

By converting the traditional pitched roofs to a flat-grassed roof the ecosystem downstream will benefit.

Stormwater from a high-density area tends to be rapid, and if not controlled it can become very destructive. Most stormwater systems direct the flow of water toward a natural water course like a river. Naturally the rain that falls in the area will run off the land and end it up in a river. The problem comes when the area is developed to be. When the land is developed into a high-density area, the rain that falls cannot infiltrate because of the impenetrable man made surfaces. This results in more of the rainfall running off the land in to the stormwater system. The stormwater system now discharges the water into rivers. The river cannot handle the large amounts of water that the stormwater systems have deposited and start eroding the riverbed. Plant life and fish are disturbed and can no longer live in the river system.

By converting the existing and future roof to flat grassed roofs, the peak amount of water that enters the stormwater system at one time is reduced. This has ecological benefits further down stream.

6.1.4 Source of Income

The flat rooftop can be used as a vegetable garden to grow vegetables and other fresh foods for the home. A surplus food produced could be sold to provide an extra income for the home. Various types of plants could be planted to generate income for the family, for example, flowers which could be sold.

6.2 OPPORTUNITIES

6.2.1 Lack of Space in Urban Residential Homes

Multitudes of people in South Africa move from rural areas to towns mainly because of the need to find work. Accommodation is limited and expensive, forcing many to live in informal homes. The municipality, in an attempt to accommodate as many as they can, provide small plots which basically can only accommodate a house and a very small garden. Lack of space within the homes and tiny surround-gardens are major problems to residents seriously limiting lifestyle. Figure 6.3 below shows a built up township in Maseru

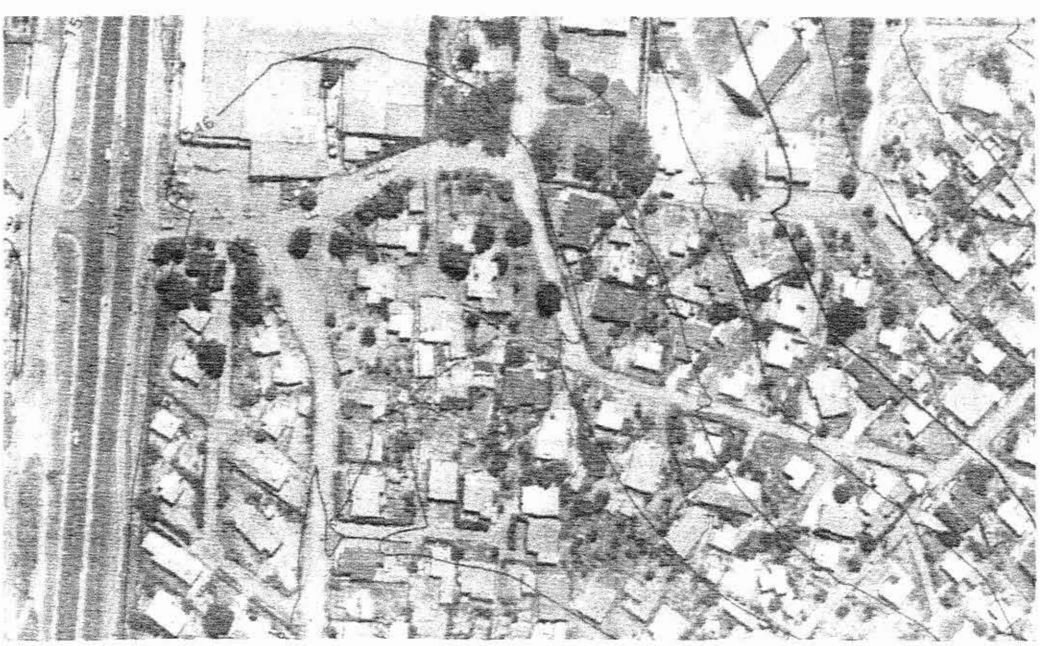


Fig 6.3 High-density Housing (Mohalalitoe, Maseru)

6.2.2 Joblessness

South Africa like many other third world countries has a problem of joblessness. There is a vast range from rich to poor people in the country. Every city of this country has lots of vagrants, and the outskirts thereof are big settlements of people living in shacks. The main problem here is joblessness.

The prevailing situation of joblessness in South Africa puts the country in an awkward position economically.

6.2.3 Environment

There is smoke rising up from everywhere in cities and surrounding residential areas - smoke from factories, from cars and from people smoking cigarette. Such conditions play a significant role in the depletion of the ozone layer as quoted in 1.3.2 and pose health hazard to people living on planet earth.

All streets and roadside walkways in cities and urban areas are paved. If houses take up the whole plot space as reflected in the survey done (chapter 4), then that means there is hardly any space left for greenery. The heat radiation that comes from this type of situation is very high.

Discharging garbage on open places as it is done in some areas, pollutes the air and makes it difficult to breath. Environment has been, and is still the great concern of the South African government. A legislation has been drawn and issued concerning environment. Everybody is required to take care of the environment around - from professionals to schoolchildren. Environmental awareness calls for everybody to be an environmentalist.

6.2.4 Crime

South Africa has a very high reported crime rate. The media show daily reports of crime happening throughout the country threatening the economy of the country.

6.2.5 Tourism

Tourism is one of the pillars of economy in South Africa especially Cape Town. For example, the provincial government of Cape Town is trying very hard to enhance the beauty of Cape Town to attract tourists. Examples are Table Mountain, Cape Point, Robben Island, 'Cape Casino', Ratanga Junction, etc.

6.3 MAKING USE OF STRENGTHS TO TAKE ADVANTAGE OF OPPORTUNITIES

6.3.1 More Space

Garden space

At the moment the current roofs have two major problems; firstly they are not environmentally friendly as discussed above, secondly they are not accessible. This is a huge waste of valuable space. In the high-density areas the emphasis is on cost that is directly related to area. The bigger the area each house occupies the more expensive the housing project. This is all quite obvious, so why then do we not utilise the area to its full potential. The roof occupies a large percentage of the area yet this entire area could as well be utilized otherwise.

This thesis aims mainly at low-cost housing schemes that take up more percentage of people staying in townships. The amount of space that the occupants have is very little. By converting their existing pitched roofs to a flat roof the amount of extra area that has been provided is almost double in some cases. People in high-density areas do not have much space around their homes to establish a garden. The roof provides an ideal location for a garden.

Extended space for Activities

The flat roof provides an extended and safe place for the children to play during the day. At the moment children have to play in the streets around their homes, this is unsafe. They can be hit by cars moving on the streets or kidnapped as is often reported in South Africa.

The flat roof provides recreational benefits for the working adults as well. At the end of a long day work they can relax on their rooftop garden. The roof top garden can be used for social functions like braais (barbecues) and other social events. This all improves the occupants' standard of living.

The C-beam environmental roof could be a solution to the crisis of congestion of houses in urban residential areas by creating more space for gardening and many other activities.

6.3.2 Job Creation

South Africa is working hard on instituting programmes to settle the problem of homelessness and clearing people living in the streets. Having not gone very far, one can see that the government with its programmes is getting somewhere because we can see houses in thousands cropping in many townships and urban areas. Therefore we can acknowledge that more people are given homes.
However, settling the problem of homelessness does not seem to solve clearing vagrants from the streets in cities and urban areas. People taken from the streets and given homes will certainly go back to the streets because of hunger - lack of jobs. An elevated crime rate is contributed to by joblessness. The main cause of this is evidently idleness and lack of job (finances).

Even though the construction part of the job comes to an end at some point, the rest of the work like greening the rooftop and taking care of plants are continual. It is the job for the owner forever.

Taking into consideration that not every house owner will be working on his house physically because other people are be working in the industry and many other places, the many people given jobs in this project will sharpen their skills in this area and continue with the construction even for other people. The spirit of entrepreneurship will be considerably revitalized within the communities as a result.

A C-Beam environmental extended roof garden can positively affect lifestyle, job creation and the national economy.

6.3.3 Environment

Covering a rooftop with vegetation can benefit the house owner/community with several good things. Environmentally, by covering rooftops in urban areas with vegetation you have increased the amount of biomass within the area. This means more vegetation to decrease the large amounts of carbon dioxide produced within the urban areas by cars, factories and other carbon dioxide producers.

Breathing clean oxygenated air is easier on the respiratory system, which in turn is essential for good health. Vegetation on the roofs will help in re-oxygenating the surrounding air through the process of photosynthesis, transforming carbon dioxide in the presence of sunlight to oxygen.

Though the air may be clean, but if it is dry, that air can be difficult to breathe. South Africa has a serious situation is this case because of its provinces whose vegetation dry up in cold seasons (winter). This becomes even more serious in the provinces at the first one or two months of spring before summer rains when the ground is dry and the wind blows. Moisture on vegetation produces evaporation that makes the air much easier to breathe and helps in cooling the surrounding areas.

The built-up areas within an urban area cause a microclimate to form. Removal of vegetation and the increase in reflective surfaces cause the ambient temperature to rise. This is why it is easier to breathe in rural areas where there is more vegetation. The vegetation absorbs the sun's harsh ultraviolet rays and reduces the amount of radiation heat reflected off the surface of the earth. In some cases, temperatures in a forest can rise up to fourteen degrees Celsius lower than the temperature of an urban area in the same vicinity. (McMarlin, 1997)

An increase in vegetation cover means that there will be a decrease in the amount of dust present in the atmosphere. Some breathing problems like asthma and certain allergies are attributed to the dust that is constantly present in large amounts in urban areas. Reducing the dust content in the air by increasing the amount of vegetation in the area will have health benefits.

Flora acts as a medium or an air filter for dust. Dust is attracted to plant leaves and sticks there until it rains. When it rains the dust particles are washed off down the stems of the plant to the ground. In certain parks the amount of dust removed from the air is up to as much as eighty five per cent less dust than that in surrounding areas.

The high demand of oxygen as a result of a lot of smoke produced by cars, factories and people smoking cigarette can be met by an improved greenery through the C-beam environmental roofing.

It is therefore quite easy to see how greening of rooftops in urban areas will dramatically benefit the environment and therefore everyone's health.

6.3.4 Crime

Security is a major problem in South Africa especially in the high-density areas. Crime is on the increase and most South Africans feel unsafe. At the moment many criminals breaking into houses use the roof as an easy entrance into the home. The existing roofs consist of corrugated iron sheeting that is easy to remove and gain access into a house. By converting the existing roofs into roof gardens a concrete slab will be used as the roof. The concrete roof, soil and vegetation will make access via the roof more difficult and help improve the homes security

This provides security for children playing on the roof as opposed to playing in the streets where there is often car accidents, shootings, kid-napping, immoral behaviours of the passers by, etc.

The do-it-yourself C-beam roof construction can be considered a tool that can directly and indirectly be used to reduce crime rate in South Africa. Considering that the root of crime is hunger and idleness, the C-beam environmental roof in its ability to provide jobs will directly keep people busy for the whole day and of course is the source of income.

6.3.5 Tourism

The aesthetic qualities of the C-beam environmental roof could be taken advantage of to attract tourists to South Africa, especially to those provinces that go dry in winter. The greenery can then be lively and attractive.

6.4 WEAKNESSES AND THREATS TO THE C-BEAM

6.4.1 Leakage

Because of its thinness (130 mm), the C-beam prestressed precast unit in jointing with others to make a roof renders the roof to many joints. Many joints on the roof increase chances of roof leakage.

6.4.2 Cost of the Project to Existing Houses' Owners

A natural tendency of people is to get a quick turnover results on everything they do. The weakness of the C-beam environmental roofing project is in its inability to bring quick and tangible benefits like money to those who desperately need it in a very short space of time. Some people are working at the moment and the point of finances is not very sound to them, it rather seems costly to employ someone to bring down their existing roofing and also to construct the C-beam roofing.

6.4.3 C-Beam Manufacturereres

The challenge that faces C-Beam as a new product is to find a manufacturer who will produce the units to the required SABS standards and quantities to cope with the needs of the people in townships.

6.4.4 Municipalities' Devotion to the Project

Municipalities are also faced with a challenge of ensuring safety and quality control of the C-Beam Environmental Roof construction, and controlling equipment for the construction.

6.4.5 A New Product

C-beam environmental roofing system is a new product that never existed before. A threat that arises from a layman's mind is 'will it work?' The natural tendency is to wait, watch and see if it works. 'If it works for so and so, then maybe I can try it' - says people often. No one wants to take a risk. The problem is not a C-beam as such, but it is 'a new product' which applies similarly to every other new thing. Naturally people tend to count the loss before everything else - 'what if it fails?'

Just because the C-beam environmental roofing system is a new product to people, it is a threat.

6.4.6 Safety and Quality Control

The engineers' and other professionals' great concern is the safety and quality control of the whole project. "Just in the name of Job creation, should residents' lives be put at risk of roof collapse where the construction is carried out by unskilled residents?" asks one engineer with a great concern.

House owners may jump with excitement when they find the opportunity of making money and staying in beautiful homes, but engineers are threatened by the safety and quality control thereof.

6.5 USING STRENGTHS TO COPE WITH THREATS AND WEAKNESSES

6.5.1 Leakage

Construction Manual

The construction manual is provided to guide builders with a detailed step-by-step ways of handling and constructing the C-beam environmental roof slab. Safety precautions are also covered in the construction manual. If followed closely, the manual will help prevent leakage of the roof.

Manufacturer's Waterproofing Instructions

The construction manual gives basics to the builder regarding waterproofing. On top of this, the manual strongly encourages the builder to stick to the manufacturer's waterproofing instructions for a specific waterproofing material that the builder will choose to use. The reason behind this is that waterproofing materials differ in use and methods of application. During trainings and seminars, the municipality can advise owners on appropriate products for waterproofing.

Mistakes do happen but sticking closely to the manufacturer's waterproofing instruction can definitely minimise chances of leakage in the roof.

Double Waterproofing

If the C-beam units are placed according to the construction manual, followed by a waterproofing placed in the joints according to the manufacturer's instructions, the roof should be watertight Placement of a well compacted smooth surfaced and water-shedding screed will enhance the waterproofing of the roof-slab.

6.5.2 Cost of C-beam to Existing Houses

The truth remains that new house builders will find the roofing system cheaper than those with existing houses because the latter have to go through the expenses of unroofing, wall preparation and roofing again with the C-beam. The cost may be reduced by using some of the roofing materials for other purposes besides the construction, e.g. roof sheets could be used as a fence around owners' home, roof truss members could be used as horizontal members of the supporting system to C-beam roofing instead of gum poles, etc.

People who are still securing their jobs now may find construction of C-beam comparatively of no financial benefit to them. But considering the time when they will be without job or retired from work doing nothing, such roofing type may be highly needed. In the former case it will obviously be needed for the production of finances and for the latter it can be needed for recreational activities.

Because the C-beam environmental roofing system is basically taking part in the government's loud voice of environmental awareness, it could possibly be incorporated as one of the environmental aid programmes. Considering its importance to both the house owners and the country as a whole, subsidy could be applied for owners of existing houses and others if possible.

6.5.3 A New Product

The main question that always arises for every new thing "will it work" could be expected in many areas of the project in this case. The following are the areas in which the C-Beam and its concept were tested:

Structurally

From the structural design point of view, the C-beam environmental roofing system can be relied upon. Appendix 1 proves mathematically that it is structurally sound. It has been proven practically in chapters 3 and 4 that it can work. Theoretical considerations discussed in chapter 5 also substantiate the technical soundness of the unit.

Popularity to People

According to the survey conducted in Cape Town and Maseru, there is a positive response from communities shown in chapter 4. Therefore if the system is structurally sound and people like it, it can be done.

C-Beam Environmental Roof Construction

The project could be well designed and liked by people, but the other question is "will it work?" meaning "can the good design be practically implemented?" This question is answered by a series of tests that were undertaken (chapter 3), from which suitable construction methods were chosen. The methods range from lifting of the C-beam units, means of transport to the rooftop, watering the roof garden to walking safely on the roof garden.

Therefore in answering the big new product's question ("will it work"), yes, it can work.

6.5.4 Safety and Quality Control

The builders will not be purely unskilled because the municipality will run seminars before allowing people to do the construction. No one will be allowed to handle the system if they did not attend the seminars and approved by the municipality. The seminars will include safety of the builders and recommended construction methods. Therefore the better word for the builders is semi-skilled.

Even though construction will be done by the community themselves, every step of construction will be approved by the municipality's professional engineer and technician. Therefore the fear of safety and quality control of the roofing system will be professionally taken care of.

6.5.5 Provision of Construction Equipment

It is obviously not a good idea for every house-owner to buy their own construction equipment to use it once (during their roof construction). It is therefore recommended that the municipality owns the equipment and rent it out to owners for construction of their roofs.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 INTRODUCTION

Southern Africa is embarking on numerous low-cost housing schemes for the homeless. The current schemes are housing many people but at the same time they are creating their own set of problems as mentioned in chapter 1. Because these housing schemes try to utilize the maximum amount of space, the homes are built very close together making the plot sizes very small - reflected in the research data analysis in chapter 4.

From a birds eye view of these schemes it can be seen that roofs occupy the majority of the area in plan. Roofs are cities' or in this case, residential areas' biggest untapped resource. With the ever-increasing cost of land, it's absurd that this space is not utilized.

The main focus of this project is to convert the existing roofs in high-density areas into the environmental roof slab. The function of the environmental roof slab is to provide a flat accessible roof where the owner can utilize this additional area for recreation and or a vegetable garden.

The environmental roof slab is intended to be constructed by the community. This means that the methods of construction used had to be simple and only require the services of the municipality to approve the construction drawings; no highly technical site supervision would be required.

The environmental roof slab solves many of the problems outlined in this project. However, there are still some problems that the environmental roof slab has to overcome to become a complete success. The biggest problem is not financial, but people's attitudes. The interpretation of the ideal home is one with the red-bricked walls and the cement roof tiles. By highlighting the benefits of the environmental roof slab, attitudes may change. The research reflects an urban residents' positive attitude towards garden extension by means of an environmental roof slab as shown in chapter 4.

7.2 TYPE OF ROOF SLAB

The ideal system for this project would be one that is light and can be lifted without the use of mechanical equipment and requires non-structural concrete topping, just a screed. A concrete screed is normally low strength concrete used to complete a floor. Appendix 1 has proven C-beam to be structurally sound for the purpose of greened flat concrete roofing.

This prestressed precast concrete will be fabricated by the manufacturer according to the South African Bureau of Standards, and will in turn sell it to house owners.

C-beam precast units can be made to span over four meters. However, it is important to check the amount of deflection on long spans for this could lead to ponding on the environmental roof slab especially where the grade of the roof is less than three percent (3%).

It is recommended that seminars be held for urban residents on how to handle, store, construct and maintain the C-beam environmental roof components.

7.3 ADVANTAGES OF THE UNIT

7.3.1 STRUCTURALLY

Weight: one of the main advantages of prestressed C-beam over reinforced concrete and other prestressed concrete systems is that, for a given span and loading, a smaller prestressed concrete C-beam is required. This saving of the dead load of the structure is particularly important for it saves concrete material for members. There is also a saving in foundation costs, and this can be a significant factor in areas of poor foundation material.

Durability: Another important strength of prestressed concrete C-beam is that by suitably placing the prestressing, the structure can be rendered crack-free, which has important implications for durability.

Thermal properties: The increased void in the C-beam unit provides superior insulation. It is recommended that insulating screed be used on top of the precast units when they are used in roofing. Soil and vegetation will also provide a natural insulation.

Differential movements: Horizontal shear and creep deformations will not be experienced in the C-beam environmental roofing because of the absence of concrete topping.

Finishes: The type of formwork or shuttering that will be used for casting the C-beam unit will be to the smooth final finish, and therefore the unit will not require any further work on it.

Speed in manufacturing: Because the units are light in weight, even in the absence of cranes the units can be shifted or moved from one place to another to create space if required. This will be of great help to the manufacturer in terms of speed of production.

7.3.2 ENVIRONMENTALLY

Environmentally:

- Reduces the amount of waste cases like carbon dioxide and carbon monoxide, which are directly linked to the depletion of the ozone layer.
- Increase in the amount of moisture making a pleasant environment.
- Reduces the micro-climate effect, by having less reflective surfaces
- Reduction in the amount of dust, this is normally particularly bad in high-density areas.

Stormwater:

- The additional vegetation will reduce the peak discharge form the area.
- Reducing the peak discharge will result in smaller stormwater pipes, therefore a cost effective.
- Less damage to the ecosystem further down-stream from siltation.

7.3.3 SOCIALLY

Aesthetics:

- Homes need to be built around the environment rather than the environment having to rebuild around homes.
- The greenery will improve the beauty of homes and urban areas as a whole.

Security:

- Thieves sometimes come in through roofs to rob, but a concrete flat roof has almost impenetrable surface.

- It provides a save place for children to play as opposed to playing on the streets where there are many car accidents and kid-napping.
- Provides a better security against fire compared to pitched roofing.

Employment: Because the whole C-beam environmental roof construction project is labour-intensive, it will create additional employment, skills and entrepreneurship spirit within the community.

Raising the standard of living: By providing more space for family activities and for growing fresh vegetables for family use and/or sales rather than always having to buy.

Community pride: If the community construct the C-beam environmental roof slab as a group, better social bonds will develop.

All the advantages mentioned above contribute significantly to the improvement of the country's economy.

7.4 SOME SHORTCOMINGS OF THE UNIT

The C-beam environmental roof like all other man-made things has some strengths and weaknesses. If strengths are not utilized to cope with the weaknesses, the construction can become a disaster. The following are the weaknesses of the system:

7.4.1 Leakage

The roof needs a careful construction and close adhesion to construction and waterproofing instructions by the constructors for it to perform at its best because of its thinness. Failure in following the instructions may lead to leakage of the roof.

7.4.2 New Product

As it is the case with every new thing, there is some natural reluctance in people to fully accept the C-beam environmental roofing just because they have not seen it working before. This therefore stands as a disadvantage to the system.

7.4.3 Safety and Quality Control

Safety and quality control are a very important aspect in this construction because it involves people's lives during and after construction. Therefore because the construction is carried out by semi-skilled constructors, the municipality may have to be strict on safety and quality control measures beginning at seminars and throughout construction.

7.5 CONCLUSION

The structural design and analysis of the C-beam is proven sound mathematically in appendix 1. In chapter 5, various areas requiring technical considerations were taken into account in the light of various design manuals and standards, basically South African Bureau of Standards.

Among the alternatives that were investigated (Light-weight Prestressed Concrete C-Beam Chapter 1, 1998), the C-Beam seemed to work out the best section considering for example, convenient section - the section unit is easy to mould, place reinforcement and cast concrete resulting in the relatively lessened amount of shuttering; Stability - the section properties allow the units to stand firm both individually and corporately as a slab/roof; Convenience in jointing - C-beam is easy to assemble and joint to one another which enhances the water-tightness of a floor/roof; Weight - C-beam is 150 kg and can be carried by 2 to 3 men. There is no need for heavy-duty machinery, therefore job opportunity is created; and aesthetics - the unit is cast to its final finishings resulting in the savings finishes.

On evaluation, C-beam has some weaknesses and threats as it is normally the case with every man-made structure, but its strengths and opportunities counter act and exceed its weaknesses especially politically, socially and economically.

The C-beam environmental roofing system is recommended in:

Industry: - prestressed precast concrete manufacturers can benefit from the unit not only because of its reduced costs, but also because communities will be buying from them.

Community: - urban residents can get more job opportunities, improved skills and revitalized spirit of entrepreneurship.

Government: - the system is recommended to be used as an aid in the environmental awareness campaign and as a tool to enhance economy.

For further research concerning the system, the following two elements are recommended:

- To investigate the capacities of municipalities concerning the implementation of the system financially, design of seminar programmes, availability of engineers and technicians to handle the project.

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APPENDICES

References		
References are to SABS 0100-1-1992 unless stated otherwise	**APP 1.1 LOADING ON SLAB**	
	Slab span 4 000 mm Finishes (screed) 1.0 kPa Live load 2.0 kPa Weight of the wall 7.125 kN/m	
	Slab to be used is prestressed C-beam, precast in 130 mm wide units, 170 mm thick and 30 minutes fire resistance is required.	
	Slab self-weight 1.470/4 = 0.368 kN/m Weight of grouted joints $\frac{10 \times 10}{2} \times 4 \Rightarrow 400\ mm^2$	
	$400 \times 10^{-6} \times 24 \times 4 = 0.038$ kN = 0.012 kN/m Total self weight = 0.380 kN/m	
	Finishes = 1.0 x 0.130 = 0.130 kN/m Live load = 2.0 x 0.130 = 0.260 kN/m Total U.D load = 0.510(dead) + 0.260(live) kN/m	0.510kN/m 0.260kN/m
SABS 0160 4.4.2	***SERVICE DESIGN MOMENT*** $M_s = (0.510 + 0.260)\frac{4^2}{8} + 7.125 \times 0.130 \times 4$ = 5.245 kNm	5.245 kNm
4.4.2 P.F.D.M. 5.3.2.2.2	***ULTIMATE DESIGN MOMENT*** $M_u = (0.510 \times 1.2 + 0.260 \times 1.6)\frac{4^2}{8} + 7.125 \times 0.130 \times 4 \times 1.2$ = 6.502 kNm	6.502 kNm
	APP 1.2 PROPERTIES OF THE SLAB	
	The design is to be in class 2 (limited tension, in cracking) Assume the wiring pattern consisting of 2 No. 9.3 mm diameter wires at height of 20mm	
	SLAB PROPERTIES Overall depth 170 mm, nominal width 130mm Cross sectional area = $(130 \times 35 \times 2) + (40 \times 100) - (\frac{90}{2} \times 5 \times 2)$ $= 12650\ mm^2$	$12650 mm^2$

	Height to centroid = 85 mm Thickness of flanges = 35 mm tapering to 30 mm Width of flanges = 95 mm Second moment of area I_{xx} = 42.53 x 10^6 mm^4 I_{yy} = 15.00 x 10^6 mm^4 Section Modulus Z_t = 500 x 10^3 mm^3 Z_b = 500 x 10^3 mm^3 Slab weight = 0.368 kN/m weight of grouted joints = 0.012 kN/m	
TABLE 28 TABLE 1	Concrete strength at transfer = 35 MPa min. (<24 Hrs) Concrete strength at 28 days = 60 MPa Concrete strength at 90 days = 64 MPa Modulus of elasticity of concrete at 28 days = 36 GPa	
3.4.2.3 P.F.D.M	***PROPERTIES OF PRESTRESSING REINFORCEMENT*** 5.0mm dia. wire: Area 19.6 mm^2 Characteristic strength = 34.7 kN Modulus of elasticity = 195 Gpa Guaranteed minimum elongation at characteristic stress for steel = 3.5%	
SABS 0100-2-1992 TABLE 5 and 3.3 TABLE 46	Silicious aggregate used Cement/water ratio of concrete = 1.9 Minimum cover to bottom steel = 20 mm Satisfactory for durability (moderate exposure) and 0.5 hours fire resistance.	
	Total area (A_s) = 2 x 19.6 = 39.2 mm^2	39.2 mm2
	Centroid of steel force (y) = $\frac{2 \times 34.7 \times 20}{2 \times 34.7}$ = 20 mm	20 mm
	Eccentricity (e) = 85 - 20 = 65 mm	65 mm

APP 1.3 ELASTIC PRESTRESS LOSSES AND STRESS AT TRANSFER

P.F.D.M.	The tendons are stressed to 80 % of their ultimate capacity (after allowances for losses due to jack friction and anchor pull-in) Initial tensile force F = 0.8 (2 x 34.7) = 55.52 kN	55.52 kN
5.8.2.2.2	Total relaxation losses = 10 % of which half occurs before transfer (at about 15 hours) hence tendon force immediately before release = 55.52 (1 - 0.1/2) = 52.74 kN	52.74 kN
	Therefore half relaxation loss = 55.52 –52.74 = 2.78 kN	2.78 kN
SABS 0100-2-92	At transfer, further losses occur due to elastic deformation of concrete. The assessment of this loss is based on the stress in concrete at the level of the wire centroid (the wires are straight). If P_i(N) is the prestress force after transfer, then the prestress loss due to elastic deformation = 52.74 kN - P_i(N)	
	But mean stress in the concrete at the wire centroid, after transfer $\delta_i = \frac{P_i}{A_c} + \frac{P_i e^2}{I_{xx}} - \frac{2}{3}\frac{M_{sw} e}{I_{xx}}$	
Eqn. 25 APP. C	$E_{ci} = 36(0.4 + 0.6 \times f_{cut}/f_{cu})$ $= 36(0.4 + 0.6 \times 35/60)$ $= 27$ GPa	27 GPa
	Elastic shortening of the concrete, δ $\delta = \delta_i \times L/E_{ci}$	
	Then the resulting loss of prestress force $= \delta \times E_s A_s/L$ $= 52.74 \times 10^3 - P_i$	
	i.e $P_i = \left[\frac{P_i}{A_c} + \frac{P_i e^2}{I_{xx}} - \frac{2 M_{sw} e}{3 I_{xx}}\right] \frac{L}{E_{ci}} \times \frac{E_s A_s}{L} = 52.74 \times 10^3 - P_i$	
	Therefore $Pi = \dfrac{52.74\times10^3 + \frac{2}{3} \times \frac{E_s A_s}{E_{ci}} \times \frac{e}{I_{xx}} \times M_{sw}}{1 + (1 + \frac{e^2 A_c}{I_{xx}}) \frac{E_s A_s}{E_{ci} A_c}}$	
	M_{sw} 0.380 x $4^2/8$ = 0.76 kNm	0.76 kNm

	$= \dfrac{52.74\times10^3 + \frac{2}{3}\times\frac{0.76\times195\times39.2}{27\times42.53}\times65}{1+(1+\frac{65^2\times12650}{42.53\times10^6})\frac{195\times39.2}{27\times12650}}$	
	$P_i = 50.413$ kN	50.413 kN
	Thus stresses at transfer a) At ends of the units $f_{ci} = P_i/A_c - P_i\,e/Z_t$ $= \dfrac{50.413\times10^3}{12650} - \dfrac{50.413\times10^3\times65}{500.35\times10^3}$	
5.3.2.3.2	$= -2.564$ MPa	-2.564 Mpa
	$f_{bi} = \dfrac{P_i}{A_c} + \dfrac{P_i\,e}{Z_b}$ $= \dfrac{50.413\times10^3}{12650} + \dfrac{50.413\times10^3\times65}{500.35\times10^3}$	
5.3.2.3.1	$= 10.534$ MPa	10.534MPa (<0.45x35) OK
5.3.2.3.1	b) At Mid span $f_{ti} = f_{ti(end)} + \dfrac{M_{sw}\times Ø}{Z_t}$ where $Ø = 1.1$ $= -2.564 + \dfrac{0.76\times1.1}{0.5}$ $= -0.892$ MPa	-0.892 Mpa (<0.45x35) OK
	$f_{bi} = f_{bi\,(end)} - \dfrac{M_{sw}\times Ø}{Z_b}$ $= 10.534 - \dfrac{0.76\times1.1}{0.5} = 8.682$ MPa	8.682 MPa

APP 1.4 CREEP/SHRINKAGE LOSSES AND FINAL STRESSES

5.8.2.5.4	The soffit stress at the ends of the unit exceeds 35/3 so an enhanced creep loss factor applies $C_f = 1 + \frac{0.25(f_{bi} - 35/3)}{(35/2 - 35/3)}$ $= 1 + \frac{0.25 \times (8.682 - 11.667)}{17.5 - 11.667} = 0.87$	0.87 %
	Mean concrete stress at the wire centroid after transfer $\delta_i = \frac{P_i}{A_c} + \frac{P_i e^2}{I_{xx}} - \frac{2}{3} \times \frac{M_{sw} e}{I_{xx}}$ $= \frac{50.413 \times 10^3}{12650} + \frac{50.413 \times 10^3 \times 65^2}{42.53 \times 10^6} - \frac{2}{3} \times \frac{0.76 \times 10^6 \times 65}{42.53 \times 10^6}$ $= 3.985 + 5.008 - 0.774$ $= 8.219$ MPa	8.219 MPa
	Assume the grout in the joints is applied when the precast unit is one month old	
5.8.2.4.4 & 5.8.2.5.5	Then 50% shrinkage and 50% creep will have occurred. If transfer takes place at one day and the unit is an inland area, take the free shrinkage strain of concrete $\epsilon_s = 310 \times 10^{-6}$	
5.8.2.4.3	Then 50% shrinkage losses $= \epsilon_{cs} \times E_s \times A_s \times 0.5 \times 10^{-3}$ $= 310 \times 10^{-6} \times 195 \times 10^3 \times 39.2 \times 0.5 \times 10^{-3}$ $= 1.185$ kN	1.185 kN
Handbook to CP110 by C&CA Fig 4.11 5.8.2.4.3	For pretensioning at 1 day, and a transfer of 40 MPa, take the creep of concrete as 60×10^{-6} per MPa stress (specific) Thus for transfer of 35 MPa, specific creep $= 48 \times 10^{-6} \times 40/35$ $= 54.86 \times 10^{-6}$ per Mpa	54.86×10^{-6} per MPA

	Thus 50% of enhanced creep losses = $S_c \times M_{\delta c} \times E_s \times A_s \times C_f \times 0.5 \times 10^{-3}$ where S_c is specific creep $M_{\delta c}$ is mean concrete stress at wire centroid C_f is creep loss factor $= 54.86 \times 10^{-6} \times 8.219 \times 195 \times 10^{3} \times 39.2 \times 1.54 \times 0.5 \times 10^{-3}$ = 1.50 kN	1.50 kN
	Assume the remaining 50% of relaxation losses also occur in the first month, then the residual prestress at 1 month $\delta_{res} = P_i$ - 0.5Relax. loss - 0.5Shr. loss - 0.5enh. Crp. loss = 50.413 - 2.78 - 1.185 - 1.50 = 44.9489 kN	44.948 kN
	The moment due to joint = $(0.01 + 0.130) \times \frac{4^2}{8}$ = 0.280 kNm	0.280 kNm
	The moment due to walls = $7.125 \times 1.2 \times \frac{4^2}{8}$ = 17.100 kNm	17.100kNm
	Total moment = 0.280 + 17.100 = 18.140 kNm	18.140 kNm
	For the purpose of calculating creep losses, none of the live load considered to be permenant (conservative assumption) Hence the total influencing creep losses = M_{sw} + moment due to joints and walls = 0.76 + 17.38 = 17.380 kNm	17.380 kNm
	and the wire stress in the concrete at the wire centroid $\delta_{conc} = \frac{\delta_{res}}{A_c} + \frac{\delta_{res}\, e^2}{I_{xx}} - \frac{2}{3} \times \frac{M_{tot}\, e}{I_{xx}}$ $= \frac{44.948 \times 10^3}{12650} + \frac{44.948 \times 10^3 \times 65^2}{42.53 \times 10^6} - \frac{2}{3} \times \frac{18.14 \times 65}{42.53}$ = -10.464 MPa	-10.464MPa
	Hence the remaining 50% creep losses $= S_c \times \delta_{conc} \times E_s \times A_s \times 0.5 \times 10^{-3} \times C_f$ $= 54.86 \times 10^{-6} \times -10.464 \times 10^{6} \times 195 \times 10^{-3} \times 39.2 \times 0.5 \times 10^{-3} \times 1.54$ = -1.909 kN	-1.909 kNm
	The remaining shrinkage loss = 1.185 kN Thus final prestress force after all losses $P_f = \delta_{res}$ - Remaining 50% Crp. - Remaining Shr. losses = 44.948 – 1.909 - 1.185 = 45.672 kN	1.185 kN 45.672 kN

	Final prestress loss $= \frac{P_i - P_f}{P_i}$ $= \frac{50.413 - 45.672}{50.413} = 9.404\%$	9.404%
TABLE 30	Then stresses in the extreme fibres of the concrete section, in the long term and uner full load are: (at mid-span) $f_t = \frac{P_f\ e\ y}{I_{xx}} - \frac{P_f}{A_c} + \frac{M_s\ y}{I_{xx}}$ $= \frac{45.672x10^3x65x85}{42.53x10^6} - \frac{45.672\ x\ 10^3}{12650} - \frac{5.245x10^3x85}{42.53x10^6}$ $= 5.933 - 3.610 - 0.010$ $= 2.313$ MPa	2.313 MPa
TABLE 29 SABS 0100-1-92	$f_b = \frac{-P_f e\ y}{I_{xx}} - \frac{P_f}{A_c} + \frac{M_s\ y}{I_{xx}}$ $= -5.933 - 3.610 + 0.010$ $= -9.533$ MPa	-9.533MPa (<0.33x64) OK
	Hence above stresses are satisfactory at service limit state	
5.3.3.1(b)	**APP 1.5 ULTIMATE LIMIT STATE**	
P.F.D.M	Allowable compressive stress in concrete at ultimate limit state $= 0.45\ x f_{cu}$ $= 0.45\ x\ 64$ $= 28.8$ MPa over the whole stress block	28.8 MPa
	For the wires 20mm above the soffit, assume them to be at 75% of the maximum allowable stress, i.e the load in each = 0.75 x 34.7 = 26.025 kN	26.025 kN
5.3.3.1(b)	Then total tensile force = 2 x 26.025 = 52.05 kN	52.05 kN
	Calculating dr : $110\ x\ 20\ x\ 28.8\ x\ 10^{-3} + 45\ x\ dr\ x\ 28.8\ x\ 10^{-3} = 52.02$ kN $63.36 + 1.296dr = 52.05$ dr = -8.727 mm	-8.727 mm
	Therefore the depth to neutral axis (x) $8.727 + 20 = 0.9x$ $x = 31.919$ mm	31.919mm

	Strain in the bottom strand due to flexure $= \frac{\text{dist. from neutral axis to the bot. steel}}{\text{dist. from neutral axis to the top outer fibre}} \times 0.0035$ $= \frac{115.21}{31.919} \times 0.0035$ $= 0.013$	0.013
	Strain in top wires, due to flexure $= \frac{19.79}{31.919} \times 0.0035$ $= 0.002$	0.002
	Stress/Strain curve for prestressing steel 5.0mm diameter $\frac{f_{pu}'}{A_s \cdot \delta_m} = \frac{34.7 \times 10^3}{19.6 \times 1.15}$ $= 1539.485$ MPa	1539.485 MPa
	$0.7 f_{pu} = 1539.485 \times 0.7$ $= 1077.640$ MPa	1077.640 MPa
	Check that total strain in the bottom steel is less than 3.5% Initial strain in steel at $0.8 \times \frac{34.7 \times 10^3}{19.6} = 1416.327$ MPa	1416.327 MPa
	$= 0.005765 - 0.012207$ $= -0.006442$	0.006442
	$0.005765 + (177/295) \times 0.006442$ $= 0.009630$	
	No compensation for losses. therefore, Strain $= 1 \times 0.009630 = 0.009630$	0.009630
	Hence, total strain at ultimate limit state $= 0.90596 \times 0.009630$ $= 0.0087$ $= 0.872\%$	0.875% (<3.5%) OK
	Centriod of tensile force, above the soffit $= \frac{\text{tensile force x displacement}}{\text{total tensile force}}$	

	$= \frac{(2 \times 33.5)/1.15 \times 20}{(2 \times 33.5)/1.15} = 20\text{mm}$	20 mm
	Centroid of compression force below the top $= \frac{11. \times 20 \times 20/2 + 45 \times 0.21 \times (20 + 0.21/2)}{11. \times 20 + 45 \times 0.21}$ $= \frac{22000 + 189.992}{2209.450} = 10.047\text{ mm}$	10.047mm
	Hence, lever arm Z = 170 - 20 - 10.047 = 139.957 mm	139.957mm
	Therefore M_u = total tensile force x Z $= 52.05 \times 139.957 \times 10^{-3}$ = 7.285 kNm	7.285kNm
	APP 1.6 SHEAR RESISTANCE	
	Check ultimate shear force, V (kN) V = {(0.510 x 1.2) + (0.260 x 1.6)}4/2 + 7.125 x 1.2 x 0.130 = 9.336 kN per 130mm width	9.336 kN
5.3.4.2.5	The critical point for uncracked shear resistance in a pretensioned section is at a distance from the face of the bearing equal to the height of the section centroid. i.e at $(\frac{\text{clear span}}{2}$ - height to centroid) $= (\frac{4000 - 120}{2}) - 85$ = 1855 mm from centre span	1855 mm
	Where V = {(0.510 x 1.2 + 0.260 x 1.6)}1.855 + 7.125 x 1.2 x 0.130 = 3.018 kN	3.018 kN
	The nominal bearing width = 120 mm, but make the appropriate allowance for spalling and inaccuracies of construction in accordance with 6.2.4.5 & 6	
6.2.4.5.1 6.2.4.5.2 c	For spalling of brick support: 25 mm For spalling of pretensioned slab: nil For inaccuracy of constructing brick supports: 4,88 x 4 =19.52 mm	

	APP 1.8 DEFLECTION	
SABS 0100-1-92 5.8.2.4.4 & 5.8.2.5.5	The following assumptions are made: 1. Transfer of prestressing force occurs one day (f_{ci} = 35 MPa) 2. The precast units are not propped 3. 50% of live load is permanent 4. The finishes and partition walls becomes effective when the slab is one month old 5. The permanent part of the live load becomes effective when the slab is three months old 6. 50% of the creep and shrinkage of the precast unit occurs in the first month 7. 70% of the creep and shrinkage of the prcast unit occurs in the first three months	
	therefore Prestressing force at three months = residual stress after 1 month $- \frac{0.2}{0.5}$ x remaining 50% creep loss + remaining shrinkage loss $= 44.948 - \frac{0.2}{0.5}(1.909 + 1.185)$ = 43.710 kN	43.710kN
TABLE 28 TABLE 28	SABS 0100:1992 gives no information concerning creep deformation relevant to hollow core slabs, nor relevant to load applied at one day. Therefore use Figure 4.11 from "Hand book on the unified code", Published by C & CA An effective Modulus of Elasticity over a given period of loading is:	
	$E_{eff} = \frac{E_i}{(1 + e_{cc} \times E_i)}$ *where E_i is the Modulus at the time of loading* *e_{cc} E_i is often called the "Creep factor", Ø*	
	Hence, the effective moduli for the various periods are: **At Transfer:** $E_{eff} = E_{ci} = 27.0 \times 10^3$ MPa	27.0×10^3 MPa
	1 - 28 days $E_{eff} = \frac{E_{ci}}{(1 + e_{cc} \times E_{ci})} = \frac{27.0 \times 10^3}{1 + 39.43 \times 10^{-6} \times 27 \times 10^3}$	

	$= 13.08 \times 10^3$ MPa	13.08×10^3 MPa
	1 - 90 day $E_{eff} = \dfrac{27.0 \times 10^3}{1 + 43.5 \times 10^{-6} \times 27 \times 10^3}$ $= 11.53 \times 103$ MPa	11.53×10^3 MPa
	1 day-long term $E_{eff} = \dfrac{27.0 \times 10^3}{1 + 68.57 \times 10^{-6} \times 27 \times 10^3}$ $= 9.47 \times 10^3$ MPa	9.47×10^3 MPa
	<u>At 28 days:</u> $E_{eff} = E_c = 36.0 \times 10^3$ MPa	36×10^3 MPa
	28 - 90 days $E_{eff} = \dfrac{E_c}{1 + \epsilon_{cc} \times E_c} = \dfrac{36.0 \times 10^3}{1 + 9 \times 10^{-6} \times 36 \times 10^3}$ $= 27.19 \times 10^3$ Mpa	27.19×10^3 MPa
	28 days-long term $E_{eff} = \dfrac{36.0 \times 10^3}{1 + 25.5 \times 10^{-6} \times 36 \times 10^3}$ $= 18.77 \times 10^3$ MPa	18.77×10^3 MPa
	<u>At 90 days:</u> $E_{eff} = E_{c\infty} = 37.44 \times 10^3$ MPa	37.44×10^3 MPa
	90 days-long term $E_{eff} = \dfrac{E_{c\infty}}{1 + \epsilon_{cc} \times E_{c\infty}} = \dfrac{37.44 \times 10^3}{1 + 16.5 \times 10^{-6} \times 37.44 \times 10^3}$ $= 23.14 \times 10^3$ MPa	23.14×10^3 MPa
	Instantaneous E_{ct} in the long term $= 38.88 \times 10^3$	38.88×10^3 MPa
	Thus, at transfer elastic shortening (δ) $\delta = \dfrac{1}{8} \times \dfrac{P_i e \times L^2}{E_{ci} \times I_c} - \dfrac{5}{48} \times \dfrac{M_{sw} \times L^2 \times \gamma_f}{E_{ci} \times I_c}$ $= \dfrac{50.413 \times 10^3 \times 65 \times 4000^2}{8 \times 27 \times 10^3 \times 42.53 \times 10^6} - \dfrac{5}{48} \times \dfrac{0.76 \times 10^6 \times 4000^2 \times 1.1}{27 \times 10^3 \times 42.53 \times 10^6}$ $\delta = 5.707 - 1.213$ $= 4.495$ mm ↑	4.495mm ↑
	Note that the ϵ_f factor of 1.1 has been applied to the dead load moment, but not to the prestress moment.	

At one month (before application of finishes and walls)

$$\delta = 5.707 \times \frac{\text{residual strength}}{P_i} \times \frac{E_{ci}}{E_{eff1-28}} - 1.213 \times \frac{E_{ci}}{E_{eff1-28}}$$

$$= 5.707 \times \frac{44.948 \times 10^3}{50.413 \times 10^3} \times \frac{27 \times 10^3}{13.08 \times 10^3} - 2.370 \times \frac{27 \times 10^3}{13.08 \times 10^3}$$

$$= 10.503 - 2.504$$

$$= 7.999 \text{ mm} \uparrow$$

7.999mm ↑

At one month (after application of finishes and walls)

Moment due to finishes = (grout joints + finishes) x 1.1 x $L^2/8$

= (0.012 + 0.130) x 1.1 x $4^2/8$

= 0.312 kNm

0.312 kNm

$$\delta = 7.999 - \frac{5}{48} \times \frac{M_f \times L^2}{E_c \times I_c} - \frac{23}{216} \times \frac{15.68 \times L^2}{E_c \times I_c}$$

$$= 7.999 - \frac{5}{48} \times \frac{0.312 \times 10^6 \times 4000^2}{36 \times 10^3 \times 42.53 \times 10^6} - \frac{23}{216} \times \frac{10.841 \times 4000^2}{36 \times 10^3 \times 42.53}$$

$$= 7.999 - 0.340 - 12.063$$

$$= -4.404 \text{ mm} \downarrow$$

-4.404 mm ↓

3.2.3.2.1.1

At 3 months (after application of 50% live load)

$$\delta = \frac{10503 \times P/S_{3month}}{\text{residual strength}} \times \frac{E_{eff1-28}}{E_{eff1-90}} - \frac{3.131 \times E_{eff1-28}}{E_{eff1-90}} - \frac{(0.340+12.063)\, E_{eff28}}{E_{eff28-90}} - \frac{5}{48} \times \frac{\text{live} \times L^2 \times 0.5 \times 10^6 \times L^2}{8 \times E_{eff90} \times I_c}$$

$$= \frac{10.503 \times 43.710}{44.948} \times \frac{13.08}{11.53} - \frac{3.131 \times 13.08}{11.53} - (0.340+12.063)\frac{36}{27.19} - \frac{5}{48} \times \frac{0.260 \times 4^2 \times 0.5 \times 10^6 \times 4000^2}{8 \times 37.44 \times 10^3 \times 42.53 \times 10^6}$$

$$= 11.587 - 3.552 - 16.431 - 0.270$$

$$= -8.658 \text{ mm} \downarrow$$

-8.658mm ↓

3.2.3.2.1.2

In the long term (including instantaneous deflection due to remain 50% live load).

$$\delta = \frac{11.587 \times P_f}{P/S_{3mnth}} \times \frac{E_{eff1-90}}{E_{eff1day}} - 3.552 \times \frac{E_{eff1-90}}{E_{eff1day\ lgt}} - \frac{16.421 \times E_{eff28-90}}{E_{eff28\ lgt}} - \frac{0272 \times E_{eff90}}{E_{eff90\ lgt}} - \frac{0.272 \times E_{eff90}}{E_{ct\ inst.}}$$

	$= \frac{11.587 \times 45.672}{43.71} \times \frac{11.53}{9.47} - \frac{3.552 \times 11.53}{9.47} - \frac{16.421 \times 27.19}{18.77} - \frac{0.272 \times 37.44}{23.14} - \frac{0.272 \times 37.44}{38.88}$ = 14.741 - 4.325 - 23.787 - 0.440 - 0.262 = -14.073 mm ↓ i.e total long term deflection below the supports = 14.073 mm > 16.0 mm, acceptable for a span of 4m.	-14.073mm ↓ Long term deflection

C-BEAM ENVIRONMENTAL ROOF QUESTIONNAIRE

1. MOVEMENTS

- When did you first come to stay here? ....
- Where did you originally come from before you stayed here ? ....
- What was the basic reason for coming to stay here?..

  ....

2. ACCOMMODATION:

- How easy was/is it to get a site (expense-wise or otherwise)? ....

  ....
- How big is your plot?..
- Type of home: (Informal) (formal).

3. GARDENING

- How big is your garden?...
- Are you satisfied by its size? ....

  ....
- Does it provide enough space for the family? ....

  ....
- Do you grow any vegetables? ....
- Do you get any surplus to sell? ....
- If it were to be extended, what could you do with the surplus? ....

  ....

  ....
- Have you got any other or enough space for other activities at home? ....
- If the garden were to be extended, how would you suggest the extension?....................

  ....

  ....

4. FLAT ROOFS

- If a flat concrete roof is to be constructed, could that be an opportunity for the extension of your garden? ....

....

- What types of plants would you grow there?...

....

- What would you do with them or use them for?...

....

- What other activities could you do on the rooftop?...

....

....

- Could this improve in any way your security?...

....

....

....

- If seminars are held for the villagers here on how to construct and maintain a concrete green rooftop, would you choose to have one? ....

....

5. JOB CREATION

- How easy was/is it to find a job?..

....

....

- Could a roof garden be of any importance to you as far as job creation is concerned?

....

....

....

- Could it be so for others around you as well?...

....

....

- What benefit could this be of to the country as a whole?...

....

....

....

6.ENVIRONMENTALLY

- How is the environment here compared to where you grew up from?

  On the land —erosion, pavings, dumping, etc.

  ....

  ....

  ....

  On people----health and otherwise

  ....

  ....

  ....

  ....

- What influence could a 'green' rooftop have environmentally?..

  ....

  ....

  ....

  ....

ROOF GARDEN QUESTIONNAIRE

Walking to and on the rooftop

- How did you feel – walking to the top of the building via the staircase? ....
  ....
- How did you feel walking on the rooftop? Towards the edges? ....
  ....
- Were you scared? ....
- Are you not afraid of heights? ....

Watering

- How did you feel – taking water with a bucket to the top of the building? And what complications does it have? ....
  ....
- Which watering method would you recommend – using hosepipe or bucket? ....
  ....
- How do you like this concept of a green rooftop? If you like it would you encourage it even to people who don't have pressure taps (taps on which hosepipe cannot work)? ....
  ....

Culture

- Does staying on the rooftop have any implications to you and your culture? ....
  ....

Growing of Crops

- Do you think many plants and vegetables can grow on the rooftop? ....
  ....
  ....

View from the Rooftop

- How did you like the view? ....
  ....

- Did you really feel higher (did the elevation have any implications on you)? ....

....

ANNEXES

C-BEAM DESIGN