ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Investigation of Alternative Forms of Precast Beam for Low Cost Buildings

Melaku Tesfaye

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By

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A Thesis submitted to

The School of Graduate Studies of Addis Ababa University

In

Partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In

STRUCTURAL ENGINEERING

Advisor

Shifferaw Taye (Ph.D.)

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Abstract

It should not be puzzling to have 55% of the condominium house lottery winners did not show up interest to sign and receive 'their' houses, which is claimed to be low cost and affordable to lower and middle class society, this figure will be larger in country side towns. This still tells us the claiming low cost houses are still far beyond the affordable limit of the target group. In this study an endeavor is made to investigate structurally safe and economical forms of precast beam. Hence a new plane truss forms of precast beam is investigated and compared to the practicing space truss form of precast beam. The new model, though it has relatively shorter length of span for the similar sizes of bar, it is found reducing the cost by around 25% and mass (weight) of the beam by 33% for relatively similar span lengths.

List of Symbols

A_c =Contact area between the section taken

A_s = Area of reinforcement computed for composite section

A_v = Area of shear reinforcement

α = Angle of inclination

b = Precast panel width

D_j = Concentrated dead load

d = Effective depth

f_c = Concrete cylindrical strength in MPa

f_y =Yield strength of reinforcement

I_c =Moment of inertia of composite section

L_j= Concentrated live load

M_d = Design moment of composite section

M_{sd} = Moment due to superimpose load

Ø = Reduction factor for shear/buckling

V=Shear force acting on section in question

V_c= Shear carrying capacity of concrete

V_n = Nominal shear strength

V_s= Nominal shear strength provided by reinforcement

V_u =Factored shear force at the section considered

W= Distributed load in kN/m

X= Distance measured from end support

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1. INTRODUCTION

1.1 General

It's estimated that 80% of the urban dwellers are living in dilapidated area where proper public facilities like access to potable water, electric power supply and emergency access etc are not properly available. This compelled the government to enhance the construction of residential apartments in slum area in different cities of the country. Since construction projects demand higher investment, it's usually difficult to curb the problem with limited resources. Still many endeavors have yet been made to introduce relatively low cost design so that to build as many houses as possible. The LCH-MH[10], which is claimed to be cost saving from the total project cost of comparable conventional building type, has put forward six integrative approaches to come up with relatively low cost houses, these are:

- Construction management consultancy system
- Phased construction system
- Modular or grid design system
- Specialized (labor based) construction system
- Manufacturing and assembling construction system
- Waste reduction system

Naturally construction industry involve many professionals of different disciplines, its known that effective implementation of one or more of the above cost reduction approaches, crystal change will be achieved.

To take part in the endeavor of making the houses more cost effective, it is intended to investigate the existing model of pre cast beam and slab block arrangements. Good experience of other countries has been taken to implement in the design and construction of grand housing development program of the country, which is still open for further investigation to enhance quality of work that meet the intended purpose.

Ministry of Works and Urban Development has launched a grand housing project in July 2004[1], yet even half of the intended 200,000 houses not finished because of different reasons. In such a of huge projects, which is claimed to be low cost, affordable to middle and lower class society and consume the lion share of the governments' budget, if slight reduction in cost and ease of work is achieved it will have a significant positive impact in saving cost and increasing investments; It also helps for transferring knowledge and skill up grading.

1.2 Objectives

This thesis research has the following objectives:

- To search for other alternative for the existing pre cast ribbed beam and floor system to make the design more cost effective and increase efficiency.
- To introduce simple and light weight pre cast beam and slab block types so that to increase quality of work and speed of construction;
- To increase productivity and minimize waste during production and construction of pre cast beam and slab block floor system.
- To check effectiveness of the current practice of pre cast beam and floor system design and construction;
- To examine the structural designs of the practicing LCH-MH approaches for the existing projects and devise the mechanism to bring about a better alternatives.

1.3 Scope

In this thesis study the modeling and analysis is done using theoretical calculations and has involve no laboratory demonstrations. Besides only the most typical reinforcement bar size (diameter 8 to 24mm) and span length of the precast beam is considered.

2. INVESTIGATION OF ALTERNATIVE PRECAST BEAM

In previous studies and current practice in design of precast beam is modeled and analyzed as space truss, where as in this studies alternative precast beam design it is investigated to model and analyze a precast beam as a plan truss. The plane truss is comprised by two horizontal longitudinal main bar connected by diagonally laid stirrups at an equal interval (spacing)

2.1 Modeling of Precast Beam

The precast beam is modeled as a plane truss like a roof truss with reinforcement as its member. This plan truss is investigated in three different stages of construction: Placement of precast beam, block laying stage, concrete pouring stage and final or working stage. In the first three stages the structure is treated as a steel structure, it's because the pre cast concrete lie in the tension zone and can be neglected due to crack formation. In the final stage since the concrete gets hardened, the structure can be treated as a usual reinforced concrete beam.

2.2 Dimension of Precast Concrete Element

Precast concrete part of the element in this model is required for the purpose of temporarily holding slab block; hence the dimension of precast element is determined based on the minimum concrete cover for moderately exposed structure as stated on EBCS-2, 1995, Table 7.2 and size of reinforcement. For the purpose of minimizing cost and weight of the element, minimum dimension is taken in all cases, but maximum reduction of cost is achieved when there is a maximum repetition, hence the width and depth of the element is set by using 20mm diameter bar and a minimum concrete cover of 15mm for all span lengths. There fore;

$$\text{Dimension} = 2 \times 15 + 20 = 50\text{mm}$$

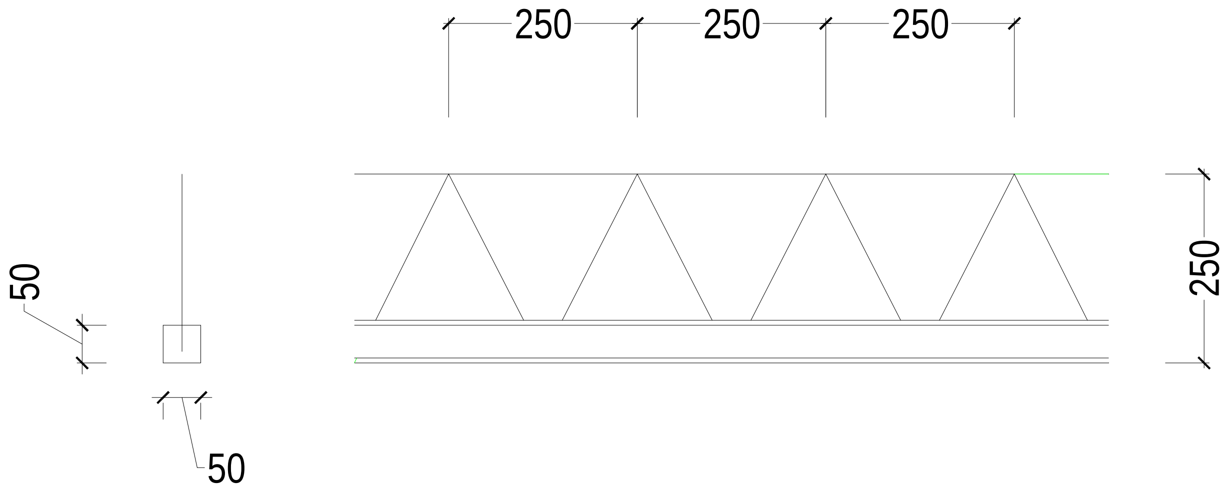

Fig. 1.1. Plan and section of plane truss model of the precast beam

2.3 Load Calculation

Since the loading is different in different stages of construction, load on precast beam is calculated in different stages of construction. [6], the following four stages of construction are considered:

a) Erection stage

On this stage of construction only self weight of the precast beam is considered as a dead load and has no live load:

Weight of precast beam=0.05×0.05×25=0.0625*kN/m*

Since the model is truss, only a concentrated load is acted on the joints, hence the calculated uniformly distributed load has to be changed to concentrated point load,

$$D_j = 0.0625 \times 0.25 = 0.0156kN$$

b) Block laying stage

On this stage self weight of precast beam and slab block is considered as a dead load and self weight of the block layer as a live load:

Dead load

Weight of precast beam=0.05×0.05×25=0.0625*kN/m*

Weight of slab block=$A_{HCB} \times \gamma_{HCB,}$ 0.0491×14=0.6874*kN/m*

Total=0.7500*kN/m*

concentrated point load,

$D_j = 0.75 \times 0.25 = 0.1876kN$

Live load

Self weight of the block layer and materials s/he might carry is assumed to be 1.1kN [8], but the maximum deflection is occurred if and only if s/he stands at the middle of the span, if a single foot covers two joints, total load is distributed to four joints,

Therefore; $L_j = \dfrac{1.1}{4} = 0.2750kN$

c) Concrete pouring stage

On this stage since the concrete is fresh it can not supports its self weight and other loads but during poring and compacting, there will be a vibration, there fore, weight of fresh concrete is considered as a live load.

Dead load

ditto as item 'b' D_j= 0.1876*kN*

Live load

Weight of fresh concrete=$A_{conc} \times \gamma_{conc}$

=0.0492×25=1.2303kN/m

concentrated point load, on the joints other than the middle four joints

$L_j = 1.2303 \times 0.25 = 0.3076kN$,

but on the middle four joints the self weight of the laborer is considered in addition to the weight of fresh concrete, hence

$L_j = 0.3076 + 0.2750 = 0.5826kN$

d) Final working stage

On this stage of construction since the concrete gets its hardness, the whole system no more considered as plane truss rather it is treated as a normal beam structure.

Dead load

weight of precast beam =0.05×0.05×25=0.0625kN/m weight of slab block $=0.0491\times14=0.6874kN/m$

cast- in-situ concrete $=0.0492\times25=1.2300kN/m$

cement screed $=t\times b\times\gamma_{conc} =0.05\times0.625\times23=0.7188kN/m$

ceiling plaster $=t\times b\times\gamma_{conc} =0.02\times0.625\times23=0.2875kN/m$

partition wall, $1kN/m^2$ $=1.000\times0.625=0.6250kN/m$

Total= 3.6112kN/m

Live load

Residential area, $2kN/m^2$ $= 2\times0.625=1.2500kN/m$

Design load,

$1.3\times3.6112+1.6\times1.2500=$**6.6946kN/m**

2.4 Analysis of Precast Beam

2.4.1 General

A precast beam is modeled and analyzed as a plane truss for the first three stages of construction. The modeling and analysis is done using an application of SAP 2000 v9.04, software.

2.4.2 Constants and assumptions

The properties of materials is in accordance to the specification of Ethiopia Building Code Standards (EBCS 2, 1995) in this study the following materials are used:

Concrete, C-25

$f_{ck}=20MPa$

$f_{cd}=11.33MPa$

$f_{ctd}=1.03MPa$

$E_{cm}=29GPa$

Steel, S-300

$f_{yd}=260.87MPa$

$Es=200GPa$

Hollow block

$\gamma_{HCB}=14kN/m^3$

2.4.3 Load Combinations

A structure, or part of a structure, is considered unfit for use when it exceeds a particular state, called a limit state, beyond which it infringes one of the criteria governing its performance or use. [3]

'Limit states can be placed in two categories:

a) The ultimate limit states are those associated with collapse, or with other forms of structural failure which may endanger the safety of people. States prior to structural collapse which, for simplicity, are considered in place of the collapse itself are also treated as ultimate limit states.

b) The serviceability limit states correspond to states beyond which specified service requirements are no longer met.' [3]

There for the load combination for this specified limit states are:

Comb1=G_k+Q_k (for serviceability)

Comb2=1.3G_k+1.6Q_k (for ultimate limit state)

2.4.3.1. **Deflection requirement for service load**

Normally the deformation resulting from direct axial stresses, compression or tension, are usually small, and hence no need to check. In case of flexural members, the deflection must be checked. However, because of large stiffness obtained from the cross section properties compared with those of shallow steel structures, the deflection in reinforced concrete structures do not govern the design. Nevertheless, there are cases in which designer should ensure that deflections be with in limits as specified by code:

a. The final deflection (including the effects of temperature, creep and shrinkage) of all horizontal members shall not, in general, exceed the value.(EBCS 2-1995, 5.2.2(1)

$$\delta = \frac{L_e}{200}$$

where, L_e = the effective span=L+d

b. For roof or floor construction supporting or attached to non structural elements (e.g. partitions and finishing, likely to be damaged by large deflections, that part of the deflection which occurs after the attachment of the non structural elements shall not exceed the value: EBCS 2-1995, 5.2.2(2)

$$\delta = \frac{L_e}{350} \leq 20mm$$

Among all loading stages, concrete pouring stages governs, hence deflection will be checked for this loading stage.

Table 2.1: Deflection of precast beam at concrete pouring stage

Span(m)	3.00	3.50	4.00	4.50	5.00	5.50	6.00
Minimum Bar size(mm)	12	12	14	20	20	24	24
Calculated max Deflection(mm)	4.66	7.99	9.86	10.74	11.99	12.51	16.99
Max. Deflection for Serviceability(mm)	8.57	10.00	11.43	12.86	14.29	15.71	17.14
Status(P/F)	P	P	P	P	P	P	P

Note:

P=pass i.e. the deflection is with in the allowable limit of deflection

F=fail, i.e. the deflection exceeds the allowable limit of deflection

2.4.3.2. Strength Requirement for serviceability at concrete poring stages

Since the concrete is fresh, it is considered as live load, because it has a dynamic nature during pouring and unable to carry loads, precast beam is still treated as a plane truss made of steel reinforcement bars as its diagonal member. The bottom chord of the truss is subjected to tensile stress while the top chord is subjected to a compressive stress.

$$N_{t,Rd} = \frac{A \times F_y}{\gamma_{M1}} \quad \text{For Tension;}$$

$$N_{b,Rd} = \frac{\chi \times \beta_A \times A \times F_y}{\gamma_{M1}} \quad \text{For buckling}$$

For main bar (longitudinal bar)

$$\chi = \frac{1}{\phi + (\phi^2 - \bar{\lambda}^2)} \leq 1$$

$$\phi = \frac{1}{2}(1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2);$$

$$\beta_A = 1$$

$$\bar{\lambda} = \frac{\lambda}{\lambda_1} \beta_A^{\frac{1}{2}}$$

$\lambda = \frac{l_e}{r}$, is the slenderness for the relevant buckling mode;

$$\lambda_1 = 93.9\varepsilon; \quad \varepsilon = \sqrt{\frac{235}{f_y}}$$

Let take a bar of $\phi = 12mm$, length, l=250mm (length between two nodes)

A=113.1mm^2, I=1017.88mm2, $r = \sqrt{\frac{I}{A}} = 3$

Slenderness, $\lambda = \frac{l_e}{r} = 83.33$

$\bar{\lambda} = \frac{\lambda}{\lambda_1}$=1

Buckling curve for round solid bars is ‘C’ (Table 4.11, EBCS-3, 1995)

Imperfection factor α for curve C is 0.49

There fore;

$\phi = 1.2$
$\chi = 0.62$
$N_{b,Rd} = 19.12kN$

The following table depicts the summary of buckling resistance of different bar sizes

Table 2.2. Buckling resistance of different sizes of bar

Bar size	10	12	14	16	20	24
A(mm^2)	78.54	113.10	153.94	201.06	314.16	452.39
I(mm^2)	490.87	1017.88	1885.74	3216.99	7853.98	16286.02
r(mm)	2.49	3.00	3.50	4.00	5.00	6.00
λ	100.40	83.33	71.43	62.50	50.00	41.67
ϕ	1.47	1.20	1.03	0.92	0.78	0.70
$\bar{\lambda}$	1.21	1.00	0.86	0.75	0.60	0.50
χ	0.46	0.62	0.74	0.84	0.98	1.07
$N_{b,Rd}$ (kN)	9.85	19.12	31.07	46.06	83.97	131.76

Table 2.3. Compressive and tensile force on the horizontal member of the truss model of precast beam

Span(m)	3.00	3.50	4.00	4.50	5.00	5.50	6.00
Bar size	12	12	14	20	20	24	24
Tensile force(kN)	11.77	15.58	19.94	31.71	30.36	36.51	42.99
Tensile resistance(kN)	30.85	30.85	41.98	85.68	85.68	123.38	123.38
Compressive force(kN)	11.77	15.58	19.94	31.71	30.36	36.40	42.99
Compressive resistance(kN)	19.12	19.12	31.07	83.97	83.97	131.76	131.76

Similar calculation is done for the diagonal members of the truss of diameter 8mm bar, and the result is tabulated as below.

For ø 8mm bar (laid diagonally as shear reinforcement);

$$l = \sqrt{\left(125^2 + 250^2\right)} = 279.51mm$$

A=50.27mm^2, I=201.06mm^2, $r = \sqrt{\frac{I}{A}} = 2$

Slenderness, $\lambda = \frac{l_e}{r} = 139.75; \; \lambda_1 = 83.11$

$$\bar{\lambda} = \frac{\lambda}{\lambda_1} = 1.68$$

$$\phi = 2.28$$
$$\chi = 0.22$$
$$N_{b,Rd} = 3.02kN$$

Table 2.4: Compressive and tensile force on the diagonal member of the truss model of precast beam

Span(m)	3.00	3.50	4.00	4.50	5.00	5.50	6.00
Tensile force(kN)	2.03	3.97	4.54	6.97	5.17	6.38	6.89
Tensile resistance(kN)	13.71	13.71	13.71	13.71	13.71	13.71	13.71
Compressive force(kN)	2.31	4.52	5.08	7.82	6.26	6.93	7.45
Compressive Resistance(kN)	3.02	3.02	3.02	3.02	3.02	3.02	3.02

As we see from the summarized table that except for a span length of 3.00m, the compressive force exceeds the compressive resistance of stirrups/ diagonal member of the plane truss model, hence if the size of reinforcement is changed to diameter 10 mm bar for the spans of 3.5m and 4.00m. The resulting compressive resistance will be 6.89kN; beyond a span of 4.0m a central supporting prop must be provided.

2.4.3.3. Strength requirement for ultimate load at final working condition

At this stage since the concrete get hardens, the system can be treated as usual reinforced concrete beam.

a. Check for Flexure

Let’s check flexural requirements for a precast beam element of span 3.00m

$$M_{\max} = \frac{wl^2}{8} = \mathbf{7.53kN\text{-}m}$$

d = 257mm

b = 50mm

to check the design to treat either as a rectangular or a Tee beam,

effective flange width of a T beam shall not exceed the lesser of is given by Art. 3.7.8 (1) EBCS 2-1995, as

$b_e \leq \left\{ b_w + \frac{1}{5} \times L \right.$ or center to center distance between support.

There fore, b_e=161mm

If we assumed that the compression stress block of rectangular shape depth of a compression stress block is given by

$$a = \frac{A_s f_{yd}}{0.85 b_e f_{cd}} = 25.9\text{mm} < h_f = 60\text{mm}$$

This implies that our assumption is correct and the section is rectangular and we can use tables and design chart of EBCS 2-1995: Part 2.

$$K_m = \frac{\sqrt{\dfrac{M_{\max}}{b}}}{d}; \quad A_s = \frac{K_s.M}{d}$$

Table2.5. Area of main (longitudinal) bar calculation

Span	3.00	3.50	4.00	4.50	5.00	5.50	6.00
M_{max} (kN-m)	7.53	10.25	13.39	16.95	20.92	25.31	33.13
$\mu_{sd,s}$	0.20	0.27	0.36	0.45	0.56	0.68	0.89
K_m	26.61	31.05	35.48	39.92	44.35	48.79	55.82
K_s	3.01	4.06	4.10	4.17	4.27	4.38	4.61
$A_{s,}$ calculated	88.19	161.93	213.61	275.03	347.58	431.35	594.28
A_s provided	$1\phi12$	$1\phi16$	$1\phi18$	$1\phi20$	$1\phi22$	$1\phi24$	$1\phi28$

As we see the maximum span used is limited on 4.50m

b. Check for Shear

Table2.6 .Design shear force

Span(m)	3.00	3.50	4.00	4.50	5.00	5.50	6.00
V_{sd} (kN)	10.04	11.72	13.39	15.06	16.74	18.41	20.08

Shear capacity of concrete is given by

$$V_c = \frac{1}{4} f_{ctd} k_1 k_2 b_w d \ ;$$

$$k_1 = 1 + 50\rho = 1.6$$

$$k_2 = 1.6 - d = 1.343$$

$$\rho = \frac{A}{bd} = 0.012$$

V_c=7.11kN<$V_{sd,}$; Therefore shear reinforcement is required

Shear resistance of a section to control diagonal compression failure is given by;

$V_{Rd} = 0.25 f_{cd} b_w d = 36.4kN$ >$V_{sd,}$

Therefore diagonal compression failure is prevented. Shear resistance of stirrups, inclined to the longitudinal reinforcement at an angle of α is given by:

$$V_s = \frac{A_v d f_{yd} (\sin\alpha + \cos\alpha)}{S}$$

$$\alpha = \tan^{-1}(\frac{250}{125}) = 63.43^{\circ}$$

We can see the shear capacity of the inclined reinforcement is a function of α, maximum resistance will be obtained if and only if $\alpha = 45$ degree, however to fulfill this requirement either the spacing of the diagonal bars or the depth of the precast beam has to be changed. Alternative has their own short coming, if the depth is reduced the deflection will be greater, and if the spacing of diagonal bar is wider, the compressive force on each bar will be greater. Hence it will be better to keep the spacing as of 250mm, there for

Shear force resisted by stirrups is: $V_s = V_{sd} - V_c = 9.68$kN

S=432mm.>d=257mm

There fore $\phi 10$ @250mm is provided

2.4.3.4. Serviceability requirement at final stage

Deflection which occurs immediately on application of load shall be computed by the usual elastic methods as the sum of the two parts δ_i and δ_{ii} given by the following equations, but not more than $\delta_{\max}$

$$\delta_i = \beta L^2 \frac{M_{cr}}{E_{cm} I_i}$$

$$\delta_{ii} = \beta L^2 \frac{M_K - M_{cr}}{0.75 E_s A_s z(d-x)}$$

$$\delta_{\max} = \beta L^2 \frac{M_k}{E_s A_s z(d-x)}$$

$$M_{cr} = 1.70 f_{ctk} Z$$

where δ_i is the deflection due to the theoretical cracking moment M_{cr} acting on the uncracked transformed section.

δ_{ii} is the deflection due to the balance of the applied moment over and above the cracking value and acting on a section with an equivalent stiffness of 75% of the cracked value.

$\delta_{\max}$ is the deflection of fully cracked section

A_s is the area of the tension reinforcement.

E_{cm} is the short term elastic modules (target modules) of the concrete.

E_s is the modules of elasticity of steel.

I_i is the moment of inertia of the uncracked transformed section.

M_k is the maximum applied moment at mid span due to sustained characteristic loads; for cantilevers M_k is the moment at the face of the support.

Z is the section modulus.

D is the effective depth of the section.

x is the neutral axis depth at the section of maximum moment

z is the internal lever arm at the section of maximum moment

β is the deflection coefficient depending on the loading and support conditions (e.g. β =5/48 for simply supported span subjected to uniformly distributed load).

Note: The value of x and z may be determined for the service load condition using a modular ratio of 10, or for the ultimate load condition.

For L=3m

Section property $A_i=A_c+nA_{st}$

$$n=\frac{E_s}{E_{cm}}=6.89$$

A_i=15077.57mm^2, x_t=161.55mm, x_b=118.45mm

$$I_{gt}=\frac{bh^3}{12}+A_c*(\frac{D}{2}-x_t)^2+nA_{st}^t d_t^2+nA_{st}^b d_b^2$$

$A_c=A_{fresh\ concrete}+A_{precast\ beam}$=51700mm^2

$I_{gt}=138.25\times10^6$mm^4

$$Z=\frac{I_{gt}}{x_b}=1.17\times10^6\text{mm}^3$$

M_{cr}=3.08kN-m, M_k=5.47kN-m

$$\rho=\frac{A_s}{bd}=0.0087$$

$$k_m=\frac{\sqrt{M_{sd}/b}}{d}=26.61,$$ k_s=3.006, k_x=0.122, and k_z=0.956

x=31.354mm and z=245.692mm

$$\delta_i=0.720\text{mm}$$

$$\delta_{ii} = 2.406\text{mm}$$

$$\delta_{\max} = 4.129\text{mm}$$

$$\delta_i + \delta_{ii} = 3.126mm < \delta_{\max} = 4.129mm$$

Allowable deflection, $\frac{L_e}{350}$=9.31mm

Since the deflection is with in the limit of allowable deflection a beam of bottom and top longitudinal reinforcement ø12 and ø10@250mm diagonal shear reinforcement satisfy both serviceability and ultimate limit state.

The following table depicts the summary for the other span lengths.

Table2.7. Deflection at the final working stage

Span (m)	**3.00**	**3.50**	**4.00**	**4.50**	**5.00**	**5.50**	**6.00**
M_k (kN-m)	5.47	7.44	9.72	12.30	15.19	18.38	21.87
k_m	26.61	31.05	35.48	39.92	44.35	48.79	55.82
k_x	0.12	0.15	0.17	0.20	0.24	0.30	0.41
k_z	0.96	0.94	0.93	0.92	0.90	0.88	0.83
x(mm)	30.84	38.55	43.69	51.40	61.68	77.10	105.37
z(mm)	246.72	241.58	239.01	236.44	231.30	226.16	213.31
δ_i (mm)	0.72	0.98	1.28	1.62	2.00	2.42	2.88
δ_{ii} (mm)	2.41	3.36	4.73	8.49	12.25	16.10	19.16
$\delta_{\max}$ (mm)	3.13	4.31	7.90	8.45	11.52	14.50	20.53
$\frac{L_e}{350}$	8.57	10.00	11.43	12.86	14.29	15.71	17.14

We can see from the table that deflection limits is not satisfied for a span beyond 5.00m, hence a beam of this model can only be has a length less than 5.50m.

3. COMPARISON OF RESULTS OF THE SPACE AND PLANE TRUSS MODEL OF PRECAST BEAM

In the previous research the precast beam is designed with a space truss model, [6] hence the result of the research in comparison with the new model, that are investigated in this study is presented with respect to

3.1 Span Length

Table 3.1. Length of span comparison of space and plane truss model of precast beam.

Minimum bar size	Space truss model		Plane truss Model
	200mm HCB	240mm HCB	220mm HCB
Ø10	3.20	3.40	
Ø12	4.00	4.20	3.00
Ø14	4.60	5.00	3.00
Ø16	5.20	5.60	3.50
Ø20	6.50	6.90	4.50
Ø24	6.60	7.50	5.50

As we see from the above table which shows the maximum span of precast beam with respect to specified bar sizes. The span obtained by a plane truss models are relatively shorter. For similar size of bar space truss models gives longer span by maximum of 40% and minimum of 24% over the plane truss models. Depth of the slab also has an effect on span length of the beam. The deeper the element, which is mainly correlated to the depth of the slab block, the longer will be the span. However the span length obtained from plan truss model is shorter; currently under construction low cost houses seldom have a span that exceed a span length of 5.00m. The provision of central props might increase the maximum span of the precast beam. As it was mentioned on technical report by Addis Ababa University, Civil Engineering Department ***'Yekatit 23 Primary School Buildings Failure Analysis and Recommendations, December 2007'*** provision of central prop is compulsory as the laboratory experiment reveals the ultimate limit condition can not be met for the precast element at the initial stage (it is concrete poring stage as per this study).

3.2 Mass of Precast Beam

Table 3.2 Mass per unit length of space and plane truss model of precast beam

Space truss model

Precast beam type	Minimum size of precast concrete		Span	Reinforcement bar provided			Mass(Kg)			
HCB	W	D	(m)	Top	Bottom	Diagonal	R-bar	concrete	Total mass	Mass / length
160	111	50	6	1Ø12	2Ø20	Ø8@200	38.88	83.25	122.13	20.36
200	119	54	6.6	1Ø12	2Ø24	Ø8@200	58.11	106.03	164.14	24.87
240	127	58	8.5	1Ø14	2Ø26	Ø8@200	89.46	156.53	245.99	28.94

Plane truss model

Precast beam type	Minimum size of Precast concrete		Span	Reinforcement provided			Mass(kg)			
HCB	W	D	(m)	Top	Bottom	Diagonal	R-bar	concrete	Total mass	Mass / length
220	50	50	3	1Ø14	1Ø14	Ø8@250	9.09	18.75	27.84	9.28
			3.5	1Ø16	1Ø16	Ø8@250	13.27	21.88	36.02	10.04
			4.5	1Ø20	1Ø20	Ø8@250	25.20	28.13	53.33	11.85
			5.5	1Ø24	1Ø24	Ø8@250	42.96	34.38	77.34	14.06

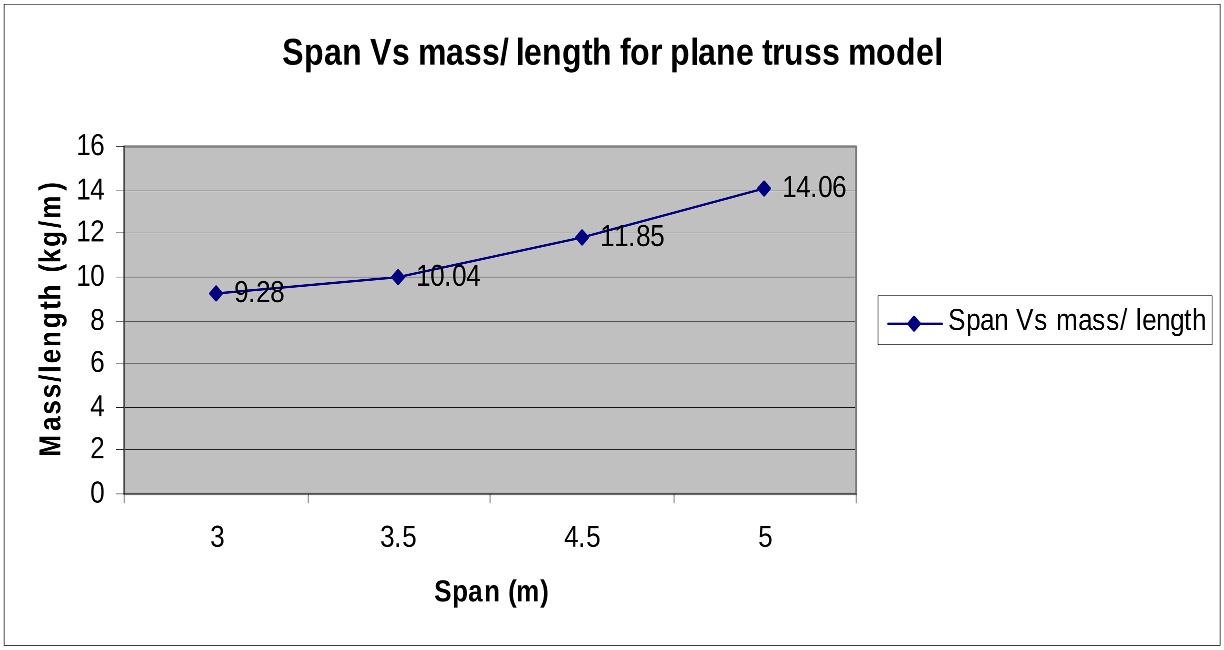

Fig.3.1: Mass per unit length Vs Span for plane truss model

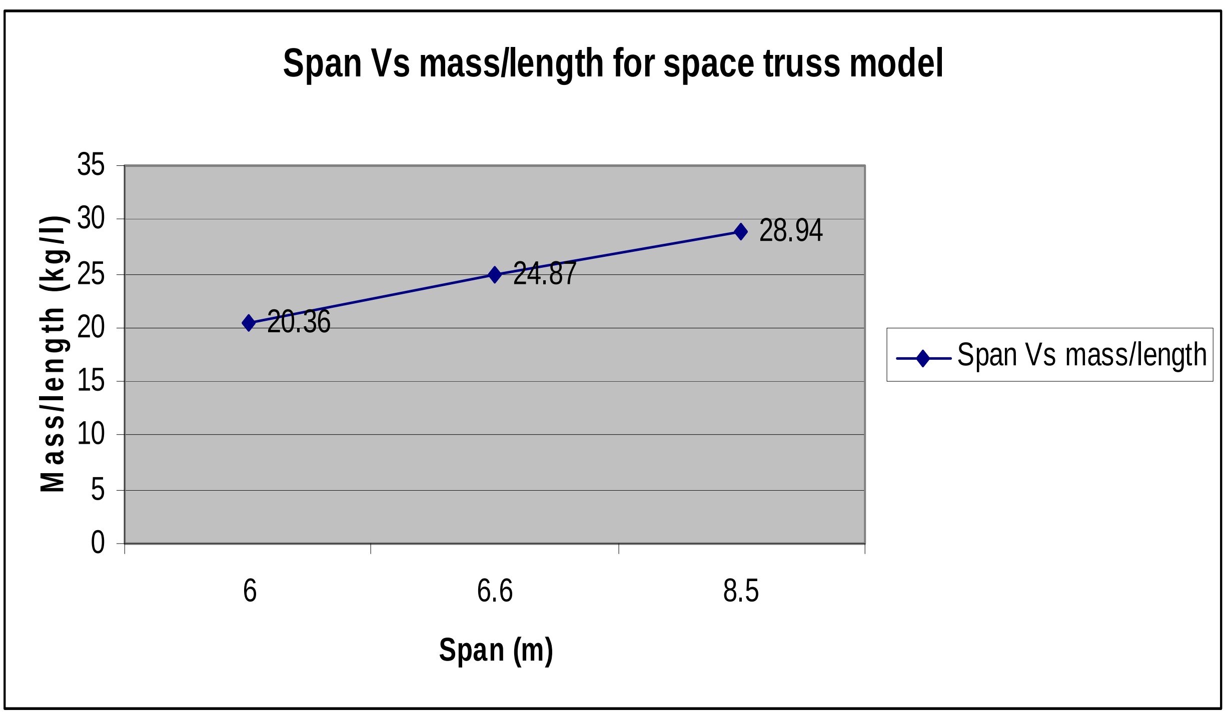

Fig. 3.2: Mass per unit length Vs span for plane truss model

Table 3.2 also shows mass per length of span since different bar sizes gives different span length suitable mechanism to compare the two model types is their mass per length. Besides as an objective of this study, it is aimed to introduce simple and light weight precast beam types so that to increase quality of work and speed of construction. In dealing with mass of the precast beam, it is just emphasized on the ease of work: the lighter the element, the faster will be the speed of work, and we can reduce time of construction and enhance material savings. However it should not be forgotten that the mass of the element has a great contribution for the stability of the structure [8].

3.3 Costs of precast beam

In comparison of costs, unit rate of items only has been taken with out consideration of installation of a production plant and/or hand tools. The unit prices of items are directly taken from the contract document for building condominium houses in the Dire Dawa City Administration, Housing Development Project Office (June, 2009):

Concrete=1078.6Birr/m^3

Reinforcement bar=10.50Birr/kg

Formwork=68Birr/m^2

Precast beam=62.7Birr/m

Slab block=76.90Birr/m^2

Therefore cost is calculated for each model of precast beam is shown in the table below:

Calculation of Costs per unit length

Space truss model

A center of center spacing of precast beam is 60cm

Dimension of precast beam			Concrete		Reinforcement bar		No. of PB per unit length	Total cost
Max span(m)	W(mm)	D(mm)	(m3)	rate	(kg)	rate		birr
6	111	50	0.03	1078.60	38.88	10.5	1.67	740.26
6.6	119	54	0.04	1078.60	58.11	10.5	1.67	1093.17
8.5	127	58	0.06	1078.60	89.46	10.5	1.67	1678.10

Plane truss model

A center of center spacing of precast beam is 55 A center of center spacing of precast beam is 60cm cm

Dimension of precast beam			Concrete		Reinforcement bar		No. of PB per unit length	Total cost
Max span(m)	W(mm)	D(mm)	(m3)	rate	(kg)	rate		birr
3	50	50	0.01	1078.60	18.75	10.5	1.80	369.31
3.5	50	50	0.01	1078.60	21.88	10.5	1.80	430.95
4.5	50	50	0.01	1078.60	28.88	10.5	1.80	568.24
5	50	50	0.01	1078.60	31.25	10.5	1.80	615.51

For ease of comparison, cost versus span length of both models, are presented graphically as follows.

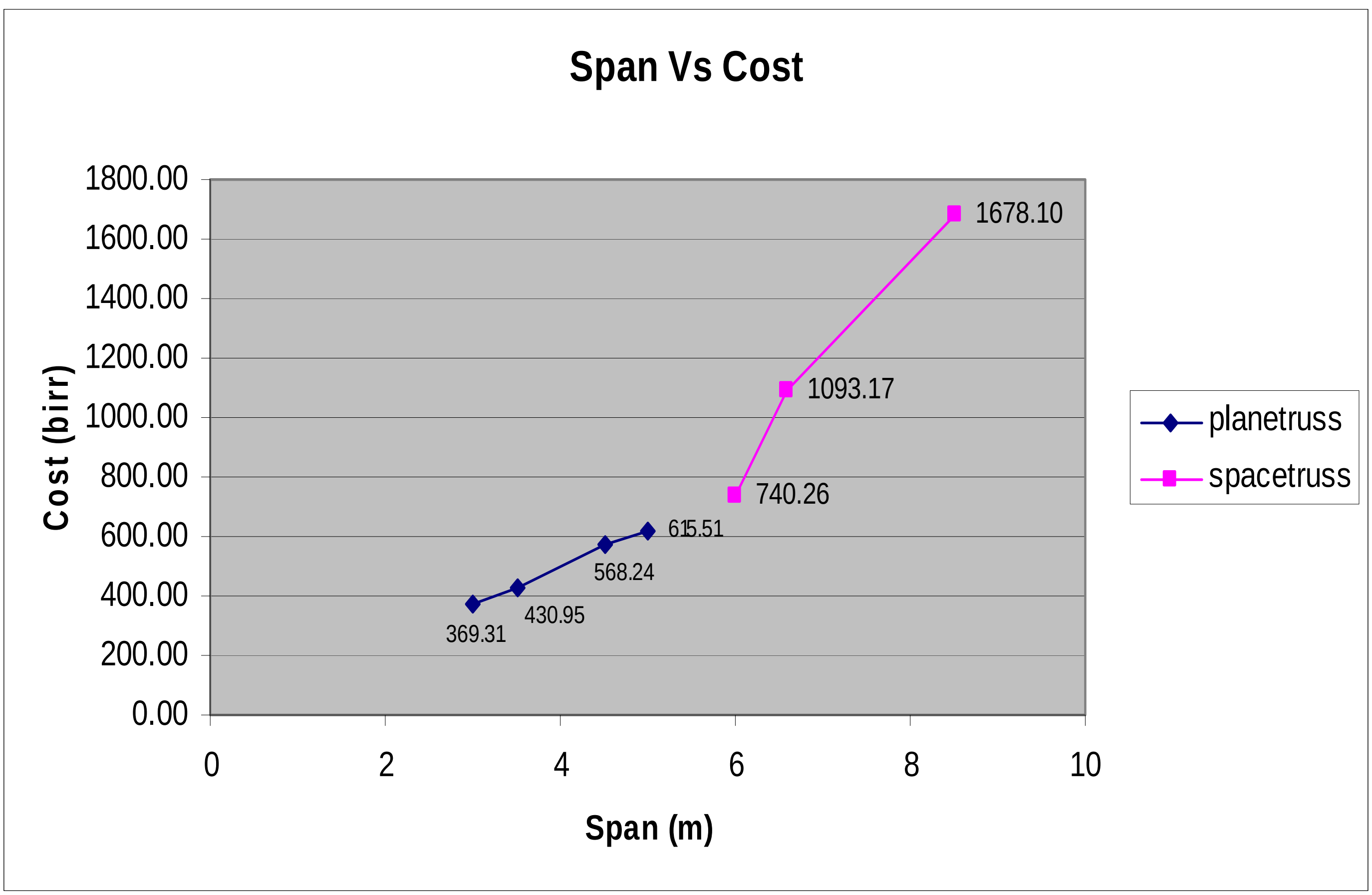

Fig. 3.3: Span Vs cost of precast beam

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The main objective of this research is to investigate a simple and light weight precast beam and slab block types to increase quality of work and speed of construction.

The result of the new model, which produce maximum of 4.5m span beam. Thought it looks shorter compared to the truss model, it is appropriate for the low cost houses, which, usually do not have a span more than this. The result also shows a space truss model of longer span are not economical.

More over the result shows the total mass of the beam is 55kg, since it is significantly, lighter weight, enhance speed of construction and save material and labor costs.
There fore:

ii. Using similar reinforcement bar, space truss model produce relatively longer span beams than plane truss model.

iii. Plane truss models, in spite of producing smaller span beams, has lighter mass per unit length of the span.

iv. The relative difference of costs – span (i.e. the slope of the cost Vs span graph) is smaller for plane truss models, while the cost –span relationship is larger for space truss models.

v. Smaller change in span will produce larger cost in case of space truss models, that is shorter span beams are more economical than the longer ones.

vi. Relatively larger change on span will produce smaller change on costs in case of plane truss; hence larger span beams are more economical.

4.2 Recommendations

Based on the study the following recommendations are made:

- This research is made based on theoretical basis, but it has to be checked by laboratory works before implementation.
- There must be a relatively controlled production quality system, since the material/element is made lighter; the heavier will be the risk in case of any quality compromises.
- Effectiveness on the new model has to be checked based on the cost of the whole structure, materials and labor, not only on a single element of precast beam.
- The new model introduced a reduced contact area between the slab block and the precast beam this requires a further investigation to check sufficiency and nature of failure of slab block.

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5. APPENDIX

A. Analysis of precast beam using SAP2000 v.9.04, out put

A. 1. Plane truss model

A. 1. 1. Span length 3.0m

TABLE: A. 1. 1 Selected Joint Displacements

Joint	Output Case	Case Type	U1	U2	U3	R1	R2	R3
Text	Text	Text	m	m	m	Radians	Radians	Radians
11	DEAD	LinStatic	0.000114	0	-0.001316	0	0.000343	0
11	COMB1	Combination	0.000381	0	-0.004505	0	0.001227	0
12	DEAD	LinStatic	0.00017	0	-0.00135	0	0.000172	0
12	COMB1	Combination	0.000576	0	-0.00463	0	0.000615	0
13	DEAD	LinStatic	0.000151	0	-0.00136	0	3.026E-18	0
13	COMB1	Combination	0.000511	0	-0.004663	0	9.918E-18	0
14	DEAD	LinStatic	0.000133	0	-0.00135	0	-0.000172	0

TABLE A.1.2 Element Forces - Frames(longitudinal members)

Frame	Station	OutputCase	CaseType	P	V2	V3	T	M2	M3
Text	m	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
34	0	DEAD	LinStatic	3.374	-0.0001482	0	0	0	0.0002606
34	0.25	DEAD	LinStatic	3.374	-0.0001482	0	0	0	0.0002976
34	0	COMB1	Combination	11.772	-0.001664	0	0	0	0.0008816
34	0.25	COMB1	Combination	11.772	0.0005127	0	0	0	0.001
35	0	DEAD	LinStatic	3.374	0.0001482	0	0	0	0.0002976
35	0.25	DEAD	LinStatic	3.374	0.0001482	0	0	0	0.0002606
35	0	COMB1	Combination	11.772	-0.0005127	0	0	0	0.001
35	0.25	COMB1	Combination	11.772	0.001664	0	0	0	0.0008816
Element Forces - (diagonal members)									
1	0	DEAD	LinStatic	-1.252	0.0009959	0	0	0	0.0001332
1	0.13975	DEAD	LinStatic	-1.252	0.0009959	0	0	0	-0.000006001
1	0.27951	DEAD	LinStatic	-1.252	0.0009959	0	0	0	-0.0001452
1	0	COMB1	Combination	-3.957	0.003028	0	0	0	0.0004263
1	0.13975	COMB1	Combination	-3.957	0.00327	0	0	0	-0.00001385
1	0.27951	COMB1	Combination	-3.956	0.003512	0	0	0	-0.0004878
2	0	DEAD	LinStatic	1.045	0.001207	0	0	0	0.0001749
2	0.13975	DEAD	LinStatic	1.045	0.001207	0	0	0	0.000006282
2	0.27951	DEAD	LinStatic	1.045	0.001207	0	0	0	-0.0001624
2	0	COMB1	Combination	3.409	0.003662	0	0	0	0.0005547
2	0.13975	COMB1	Combination	3.409	0.003904	0	0	0	0.00002602

A. 1. 2. Span length 3.5m

TABLE:A.1.3 Selected Joint Displacements

Joint	Output Case	Case Type	U1	U2	U3	R1	R2	R3
Text	Text	Text	m	m	m	Radians	Radians	Radians
14	DEAD	LinStatic	0.000265	0	-0.002388	0	0.000226	0
14	COMB1	Combination	0.000872	0	-0.00795	0	0.000784	0
15	DEAD	LinStatic	0.000239	0	-0.002401	0	6.859E-18	0
15	COMB1	Combination	0.000786	0	-0.007993	0	2.408E-17	0
16	DEAD	LinStatic	0.000214	0	-0.002388	0	-0.000226	0

TABLE: A.1.4 Element Forces –on the Selected Frames(longitudinal members)

Frame	Station	Output Case	Case Type	P	V2	V3	T	M2	M3
Text	m	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
40	0	COMB1	Combination	-15.581	-0.001088	0	0	0	0.0012
40	0.25	COMB1	Combination	-15.581	0.001088	0	0	0	0.0012
54	0	COMB1	Combination	15.581	-0.001666	0	0	0	0.0012
54	0.25	COMB1	Combination	15.581	0.0005105	0	0	0	0.0013
55	0	DEAD	LinStatic	4.593	0.000149	0	0	0	0.0003854
55	0.25	DEAD	LinStatic	4.593	0.000149	0	0	0	0.0003482
55	0	COMB1	Combination	15.581	-0.0005105	0	0	0	0.0013
55	0.25	COMB1	Combination	15.581	0.001666	0	0	0	0.0012

Element Forces - Frames (diagonal members)

1	0	COMB1	Combination	-4.515	0.003534	0	0	0	0.0004925
1	0.13975	COMB1	Combination	-4.514	0.003776	0	0	0	-0.00001832
1	0.27951	COMB1	Combination	-4.514	0.004018	0	0	0	-0.0005629
2	0	COMB1	Combination	3.968	0.004279	0	0	0	0.0006433
2	0.13975	COMB1	Combination	3.968	0.00452	0	0	0	0.00002847
2	0.27951	COMB1	Combination	3.967	0.004762	0	0	0	-0.0006202
28	0	COMB1	Combination	-4.514	-0.004018	0	0	0	-0.0005629
28	0.13975	COMB1	Combination	-4.514	-0.003776	0	0	0	-0.00001832
28	0.27951	COMB1	Combination	-4.515	-0.003534	0	0	0	0.0004925

A. 1. 3. Span length 4m

TABLE:A.1.5 Selected Joint Displacements								
Joint	Output Case	Case Type	U1	U2	U3	R1	R2	R3
Text	Text	Text	m	m	m	Radians	Radians	Radians
17	COMB1	Combination	0.000924	0	-0.00982	0	0.000747	0
18	DEAD	LinStatic	0.000262	0	-0.003023	0	-1.163E-17	0
18	COMB1	Combination	0.000843	0	-0.009861	0	-3.856E-17	0
19	DEAD	LinStatic	0.000238	0	-0.003011	0	-0.000219	0
19	COMB1	Combination	0.000762	0	-0.00982	0	-0.000747	0

TABLE: A.1.6 Element Forces –on the Selected Frames(longitudinal members)									
Frame	Station	OutputCase	CaseType	P	V2	V3	T	M2	M3
Text	m	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
45	0	COMB1	Combination	-19.937	-0.001481	0	0	0	0.0022
45	0.25	COMB1	Combination	-19.937	0.001481	0	0	0	0.0022
61	0	COMB1	Combination	19.936	-0.002095	0	0	0	0.0021
61	0.25	COMB1	Combination	19.936	0.0008668	0	0	0	0.0023
62	0	COMB1	Combination	19.936	-0.0008668	0	0	0	0.0023
62	0.25	COMB1	Combination	19.936	0.002095	0	0	0	0.0021
Element Forces - Frames (diagonal members)									
2	0	COMB1	Combination	-5.082	0.00462	0	0	0	0.0006541
2	0.13975	COMB1	Combination	-5.082	0.004862	0	0	0	-0.00000848
2	0.27951	COMB1	Combination	-5.081	0.005104	0	0	0	-0.0007049
3	0	COMB1	Combination	4.537	0.005154	0	0	0	0.0007612
3	0.13975	COMB1	Combination	4.536	0.005396	0	0	0	0.00002401
3	0.27951	COMB1	Combination	4.536	0.005637	0	0	0	-0.0007469

A.1.4. Span length 4.5m

TABLE:A.1.7 Selected Joint Displacements								
Joint	**Output Case**	**CaseType**	**U1**	**U2**	**U3**	**R1**	**R2**	**R3**
Text	Text	Text	m	m	m	Radians	Radians	Radians
19	COMB1	Combination	0.000825	0	-0.010708	0	0.000612	0
20	DEAD	LinStatic	0.000182	0	-0.002568	0	4.137E-18	0
20	COMB1	Combination	0.000762	0	-0.01074	0	2.042E-17	0
21	DEAD	LinStatic	0.000167	0	-0.002561	0	-0.000146	0
21	COMB1	Combination	0.000699	0	-0.010708	0	-0.000612	0

TABLE:A.1.8 Element Forces –on the Selected Frames(longitudinal members)									
Frame	**Station**	**Output Case**	**Case Type**	**P**	**V2**	**V3**	**T**	**M2**	**M3**
Text	m	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
89	0	DEAD	LinStatic	-3.796	1.11E-16	0	0	0	0.000409
89	0.25	DEAD	LinStatic	-3.796	1.11E-16	0	0	0	0.000409
89	0	COMB1	Combination	-14.742	-0.00148	0	0	0	0.0016
89	0.25	COMB1	Combination	-14.742	0.001481	0	0	0	0.0016
108	0	DEAD	LinStatic	3.796	8.38E-05	0	0	0	0.000418
108	0.25	DEAD	LinStatic	3.796	8.38E-05	0	0	0	0.000397
108	0	COMB1	Combination	14.741	-0.00109	0	0	0	0.0016
108	0.25	COMB1	Combination	14.741	0.001875	0	0	0	0.0015
TABLE: Element Forces - Frames (diagonal members)									
2	0	COMB1	Combination	-7.824	0.008251	0	0	0	0.0012
2	0.13975	COMB1	Combination	-7.824	0.008493	0	0	0	1.13E-05
2	0.27951	COMB1	Combination	-7.823	0.008734	0	0	0	-0.0012
3	0	COMB1	Combination	6.971	0.008399	0	0	0	0.0012
3	0.13975	COMB1	Combination	6.97	0.008641	0	0	0	2.14E-05
3	0.27951	COMB1	Combination	6.97	0.008882	0	0	0	-0.0012

A.1.5. Span length 5m

TABLE: A.1.9 Selected Joint Displacements								
Joint	**Output Case**	**Case Type**	**U1**	**U2**	**U3**	**R1**	**R2**	**R3**
Text	Text	Text	m	m	m	Radians	Radians	Radians
21	COMB1	Combination	0.000847	0	-0.011958	0	0.000588	0
22	DEAD	Lin Static	0.00025	0	-0.003761	0	1.851E-17	0
22	COMB1	Combination	0.000786	0	-0.011989	0	5.298E-17	0
23	DEAD	Lin Static	0.000231	0	-0.003752	0	-0.000175	0
23	COMB1	Combination	0.000726	0	-0.011958	0	-0.000588	0

TABLE: A.1.10 Element Forces –on the Selected Frames(longitudinal members)									
Frame	**Station**	**Output Case**	**Case Type**	**P**	**V2**	**V3**	**T**	**M2**	**M3**
Text	m	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
55	0	DEAD	Lin Static	-9.362	0	0	0	0	0.0022
55	0.25	DEAD	Lin Static	-9.362	0	0	0	0	0.0022
55	0	COMB1	Combination	-30.363	-0.003023	0	0	0	0.0073
55	0.25	COMB1	Combination	-30.363	0.003023	0	0	0	0.0073
76	0	DEAD	Lin Static	9.362	0.0002149	0	0	0	0.0022
76	0.25	DEAD	Lin Static	9.362	0.0002149	0	0	0	0.0022
76	0	COMB1	Combination	30.361	-0.002442	0	0	0	0.0074
76	0.25	COMB1	Combination	30.361	0.003603	0	0	0	0.0072
Element Forces - Frames (diagonal members)									
2	0	COMB1	Combination	-6.256	0.006657	0	0	0	0.000955
2	0.13975	COMB1	Combination	-6.255	0.006899	0	0	0	8.11E-06
2	0.27951	COMB1	Combination	-6.255	0.007141	0	0	0	-0.00097
3	0	COMB1	Combination	5.707	0.006792	0	0	0	0.000984
3	0.13975	COMB1	Combination	5.707	0.007034	0	0	0	1.76E-05
3	0.27951	COMB1	Combination	5.706	0.007276	0	0	0	-0.00098

A.1.6. Span length 5.5m

TABLE: A.1.11 Selected Joint Displacements								
Joint	**Output Case**	**Case Type**	**U1**	**U2**	**U3**	**R1**	**R2**	**R3**
Text	Text	Text	m	m	m	Radians	Radians	Radians
23	COMB1	Combination	0.000774	0	-0.012469	0	0.000611	0
24	DEAD	LinStatic	0.00023	0	-0.003945	0	2.596E-17	0
24	COMB1	Combination	0.000715	0	-0.012506	0	0.000097	0
25	DEAD	LinStatic	0.000215	0	-0.003937	0	-0.000151	0
25	COMB1	Combination	0.000673	0	-0.012493	0	-0.00042	0

TABLE: A.1.12 Element Forces –on the Selected Frames(longitudinal members)									
Frame	**Station**	**Output Case**	**Case Type**	**P**	**V2**	**V3**	**T**	**M2**	**M3**
Text	m	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
60	0	DEAD	LinStatic	-11.318	0	0	0	0	0.0039
60	0.25	DEAD	LinStatic	-11.318	0	0	0	0	0.0039
60	0	COMB1	Combination	-36.399	-0.003634	0	0	0	0.0133
60	0.25	COMB1	Combination	-36.399	0.005071	0	0	0	0.0132
82	0	DEAD	LinStatic	11.318	-0.0002493	0	0	0	0.0039
82	0.25	DEAD	LinStatic	11.318	-0.0002493	0	0	0	0.004
82	0	COMB1	Combination	36.51	-0.005331	0	0	0	0.013
82	0.25	COMB1	Combination	36.51	0.003375	0	0	0	0.0133
83	0	DEAD	LinStatic	11.318	0.0002493	0	0	0	0.004
83	0.25	DEAD	LinStatic	11.318	0.0002493	0	0	0	0.0039
83	0	COMB1	Combination	36.285	-0.0003037	0	0	0	0.0134
83	0.25	COMB1	Combination	36.285	0.008402	0	0	0	0.0124
Element Forces - Frames (diagonal members)									
2	0	COMB1	Combination	-6.818	0.007487	0	0	0	0.0011
2	0.13975	COMB1	Combination	-6.818	0.007729	0	0	0	1.201E-05
2	0.27951	COMB1	Combination	-6.817	0.00797	0	0	0	-0.0011
3	0	COMB1	Combination	6.265	0.007521	0	0	0	0.0011
3	0.13975	COMB1	Combination	6.264	0.007762	0	0	0	1.535E-05
3	0.27951	COMB1	Combination	6.264	0.008004	0	0	0	-0.0011

A.1.7. Span length 6m.

TABLE: A.1.13 Selected Joint Displacements								
Joint	**Output Case**	**Case Type**	**U1**	**U2**	**U3**	**R1**	**R2**	**R3**
Text	Text	Text	m	m	m	Radians	Radians	Radians
24	COMB1	Combination	0.00081	0	-0.016839	0	0.001168	0
25	DEAD	LinStatic	0.000318	0	-0.0054	0	0.000175	0
25	COMB1	Combination	0.000988	0	-0.016956	0	0.000582	0
26	DEAD	LinStatic	0.000299	0	-0.005409	0	2.291E-17	0
26	COMB1	Combination	0.000929	0	-0.016986	0	6.443E-17	0
27	DEAD	LinStatic	0.00028	0	-0.0054	0	-0.000175	0
27	COMB1	Combination	0.000869	0	-0.016956	0	-0.000582	0
28	DEAD	LinStatic	0.000336	0	-0.005365	0	-0.000349	0
28	COMB1	Combination	0.001047	0	-0.016839	0	-0.001168	0

TABLE:A.1.14 Element Forces –on the Selected Frames(longitudinal members)									
Frame	**Station**	**Output Case**	**Case Type**	**P**	**V2**	**V3**	**T**	**M2**	**M3**
Text	m	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
65	0	DEAD	LinStatic	-13.471	1.776E-15	0	0	0	0.0046
65	0.25	DEAD	LinStatic	-13.471	1.776E-15	0	0	0	0.0046
65	0	COMB1	Combination	-42.992	-0.004353	0	0	0	0.015
65	0.25	COMB1	Combination	-42.992	0.004353	0	0	0	0.015
90	0	DEAD	LinStatic	13.471	0.0002493	0	0	0	0.0046
90	0.25	DEAD	LinStatic	13.471	0.0002493	0	0	0	0.0045
90	0	COMB1	Combination	42.99	-0.00383	0	0	0	0.0151
90	0.25	COMB1	Combination	42.99	0.004876	0	0	0	0.015
Element Forces - Frames (diagonal members)									
2	0	DEAD	LinStatic	-2.493	0.002816	0	0	0	0.0003957
2	0.13975	DEAD	LinStatic	-2.493	0.002816	0	0	0	2.217E-06
2	0.27951	DEAD	LinStatic	-2.493	0.002816	0	0	0	-0.0003913
2	0	COMB1	Combination	-7.445	0.008236	0	0	0	0.0012
2	0.13975	COMB1	Combination	-7.444	0.008478	0	0	0	1.172E-05
2	0.27951	COMB1	Combination	-7.444	0.00872	0	0	0	-0.0012
3	0	DEAD	LinStatic	2.286	0.002836	0	0	0	0.0003997
3	0.13975	DEAD	LinStatic	2.286	0.002836	0	0	0	3.372E-06
3	0.27951	DEAD	LinStatic	2.286	0.002836	0	0	0	-0.0003929
3	0	COMB1	Combination	6.892	0.008283	0	0	0	0.0012
3	0.13975	COMB1	Combination	6.892	0.008525	0	0	0	0.0000159
3	0.27951	COMB1	Combination	6.891	0.008767	0	0	0	-0.0012
4	0	DEAD	LinStatic	-2.295	0.002727	0	0	0	0.0003895
4	0.13975	DEAD	LinStatic	-2.295	0.002727	0	0	0	8.399E-06
4	0.27951	DEAD	LinStatic	-2.295	0.002727	0	0	0	-0.0003727
4	0	COMB1	Combination	-6.905	0.007981	0	0	0	0.0012
4	0.13975	COMB1	Combination	-6.904	0.008223	0	0	0	2.978E-05
4	0.27951	COMB1	Combination	-6.904	0.008464	0	0	0	-0.0011

B. Mass calculation of precast beam

Table:B.1.1 Mass per unit length of precast beam

Space truss model

Beam size		Reinforcement bar(kg)		Length of bar(m)	Mass per unit length of (kg/m)	
W(mm)	111	Top	1∅12	6.21	Reinforcement bar	6.71
D(mm)	50	Bottom	2∅20	6.21	Concrete	13.88
Span(m)	6.0	Diagonal	31∅8@200mm	0.34	Total	20.59
Beam size		Reinforcement bar(kg)		Length of bar(m)	Mass per unit length of (kg/m)	
W(mm)	119	Top	1∅12	6.81	Reinforcement bar	8.93
D(mm)	54	Bottom	2∅24	6.81	Concrete	16.07
	6.6	Diagonal	34∅8@200	0.34	Total	25.00
Beam size		Reinforcement bar(kg)		Length of bar(m)	Mass per unit length of (kg/m)	
W(mm)	127	Top	1∅14	8.71	Reinforcement bar	10.47
D(mm)	58	Bottom	2∅26	8.71	Concrete	18.42
Span(m)	8.5	Diagonal	44∅8@200	0.34	Total	28.89

Plane truss model

Beam size		Reinforcement bar(kg)		Length of bar(m)	Mass per unit length of (kg/m)	
W(mm)	50	Top	1∅14	3.21	Reinforcement bar	3.47
D(mm)	50	Bottom	1∅14	3.21	Concrete	6.25
Span(m)	3.0	Diagonal	12∅8@250mm	0.56	Total	9.72
Beam size		Reinforcement bar(kg)		Length of bar(m)	Mass per unit length of (kg/m)	
W(mm)	50	Top	1∅16	3.71	Reinforcement bar	4.23
D(mm)	50	Bottom	1∅16	3.71	Concrete	6.25
Span(m)	3.5	Diagonal	14∅8@250mm	0.56	Total	10.48
Beam size		Reinforcement bar(kg)		Length of bar(m)	Mass per unit length of (kg/m)	
W(mm)	50	Top	1∅20	4.71	Reinforcement bar	6.05
D(mm)	50	Bottom	1∅20	4.71	Concrete	6.25
Span(m)	4.5	Diagonal	18∅8@250mm	0.56	Total	12.30
Beam size		Reinforcement bar(kg)		Length of bar(m)	Mass per unit length of (kg/m)	
W(mm)	50	Top	1∅24	5.21	Reinforcement bar	8.28
D(mm)	50	Bottom	1∅24	5.21	Concrete	6.25
Span(m)	5.0	Diagonal	20∅8@250mm	0.56	Total	14.53

C. Figures

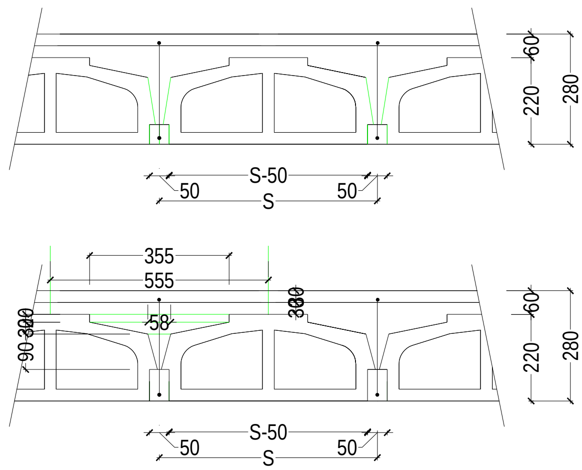

Fig. C.1: Plane truss model of precast beam and slab block arrangements

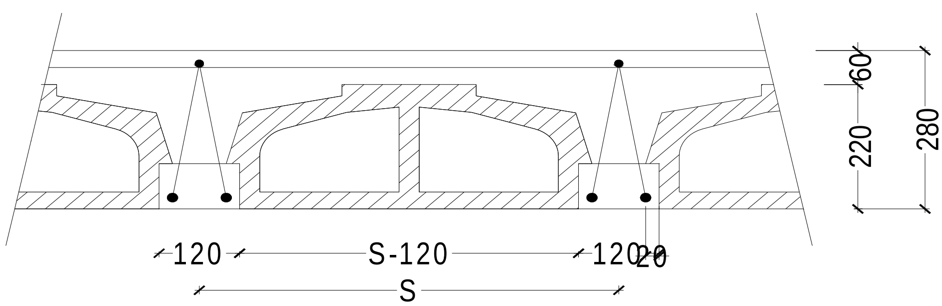

Fig. C.2: Space truss model of precast beam and slab block arrangements

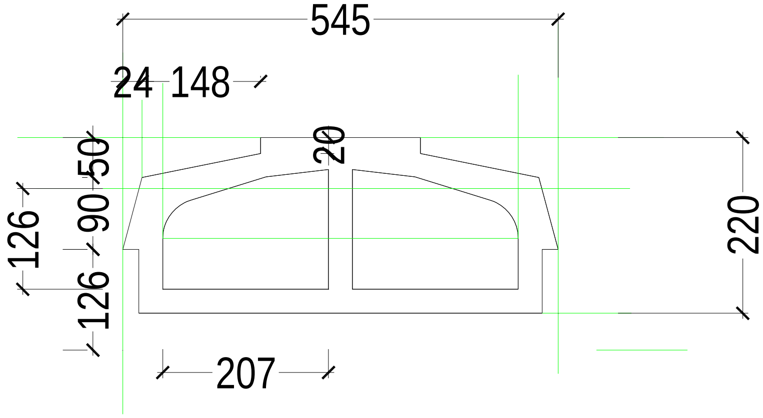

Fig. C.3: Slab block type used for floor slabs

Declaration

I, the undersigned, declare that this thesis is my original work, it has not been presented for a degree and that all source of materials used for this thesis has been duly acknowledged

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Signature:

Place: Addis Ababa University, Faculty of Technology

Date of Submission: November, 2009