EXPERIMENTAL AND THEORETICAL STUDY OF PRECAST BEAM-SLAB CONSTRUCTION

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ABSTRACT

The use of partially precast beam elements with shear connectors in slab construction relieves the requirement of extensive use of soffit formwork and props and will have the advantage of faster construction. It also reduces adverse effects associated deforestation.

Experimental and theoretical investigations were conducted to study the strength and deformation characteristics of two types of precast slab systems. Type A slab is with 50 mm topping while type B slab is without topping.

Part of the experimental program was dedicated to the study of mix design for the production of suitable hollow concrete beam tiles which bridge the space between the precast beam elements. The second part of the test program included the study of the precast beam element alone in order to investigate the response under load of the precast slab while the cast in-situ concrete is still in its plastic state. The third part of the experimental program was concerned with full size slab testing. Theoretical investigations were conducted parallel to the experimental investigations.

Comparison of the results showed very good agreement leading to the conclusion that basic mechanics of reinforced concrete can be used for design and analysis of precast beams and/or precast slab systems.

INTRODUCTION

Background and identification of problems

The role of reinforced concrete as the major building material for almost all kinds of construction has already been recognized in our country. This may be attributed to the availability of most of the constituent materials in all parts of the country at low cost locally or at small distances from the construction site and cheap labor for mixing and placing concrete. Additional advantages derived from the use of such building material is the facility with which it can be deposited and made to fill forms or moulds of almost any practical shape while it is still fresh, and its high fire and weather resistance after it has hardened.

However, the extensive use of formwork consisting of primarily timber tends to make it more and more unsuitable, because of the serious environmental impact associated with deforestation and increase in cost of concrete as a result of the extensive use of timber as formwork.

Unfortunately, the use of steel formwork could not yet be considered as an immediate substitute for timber formwork because of its high cost.

Objective

Fully cast-in place concrete slabs not only require extensive use of soffit formwork and props for casting, but also longer period of time for the removal of the formwork. Thus avoiding the use of formwork in slabs will have the advantage of faster construction with subsequent reduction in the cost of construction, reducing adverse effects associated with deforestation, achieving even soffit finish requiring less plastering, etc.

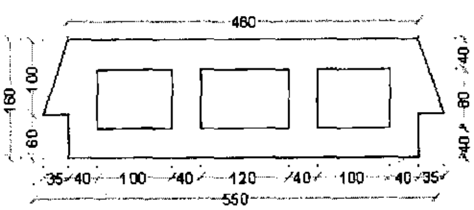
One of the most efficient solutions, that have found wide application in many countries, is the use partially precast beam with shear connectors, as formwork in lieu of timber or steel formwork [1]. In such type of construction, the fresh concrete can be directly poured on the precast beam elements and hollow concrete blocks, which bridge the space between the beams.

However, the safety of such construction must be ensured through theoretical investigations supported by experimental verifications. The purpose of the study is therefore, to investigate the strength and deformation characteristics of the precast beam-slab system as a unit as well as its components.

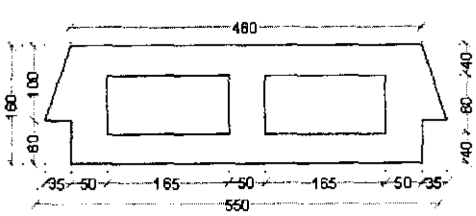
PRODUCTION OF HOLLOW CONCRETE BLOCKS

Proposed shapes for hollow concrete blocks

Two alternative shapes of hollow concrete blocks were proposed. The first one is a two-celled unit with a total depth of 160mm and width of 200mm. The second is three celled with the same external dimensions as the two celled unit. The steel moulds for both shapes are not currently available in the market, so they were designed and fabricated in the Faculty's workshop. The shapes and their respective dimensions of the two types of hollow concrete blocks are shown in Fig. 1.



(a) two celled



(b) three celled

Figure 1 Shapes of hollow concrete blocks

Material selection for production of hollow concrete block

For handling and reduction in dead weight, the hollow blocks are required to be light in weight. Thus, for the mix design lightweight aggregates were used, where at least the course component was lightweight. Two types of lightweight coarse aggregates have been identified; pumice and scoria. In designing the preliminary mix proportions combinations of fine component of one material with course component of the other material have been proposed as shown in Table 1.

Table 1: Aggregate composition and designation

No	Aggregate Compositions	Designation
1	Pumice coarse aggregate and Pumice fine aggregate	PP
2	Pumice coarse aggregate and Sand fine aggregate	PSa
3	Scoria coarse aggregate and Pumice fine aggregate	ScPu
4	Scoria coarse aggregate and Sand fine aggregate	ScSa
5	Scoria coarse aggregate and Scoria fine aggregate	ScSc

Mix design of hollow concrete blocks

After many trial mixes, suitable mixes were selected as shown in Tables 2 and 3 for the two celled and three celled hollow concrete blocks respectively. The cement used is Portland Pozzolana Cement (PPC) from Mugar cement factory and tap water was employed for all mixes. With each mix type, 9 cube and 6 hollow concrete block specimens were cast. The cubes were then cured in a water tank at laboratory conditions and tested for strength at 3, 7 and 28 days. The hollow blocks were cured three times per day under shade until the age of 14 days after casting.

Table 2: Mix design for hollow concrete blocks with two cells

No	Mix Type	Date of Mixing	Course Aggregate	Fine Aggregate	Mix proportion in kg/m^3 of concrete				W/C ratio	Slump (mm)	Remark
					Cement	Coarse Agg.	Fine Agg.	Water			
1	PP 1	18/12/01	Pumice	Pumice	288	509	433	150	0.52	0	
2	PP 2	21/12/01	Pumice	Pumice	313	504	413	150	0.48	2	
3	Psa	25/12/01	Pumice	Sand	288	528	324	150	0.52	0	
4	ScSc	02/01/02	Scoria	Scoria	313	477	390	150	0.48	0	Failed
5	ScSa 1	04/01/02	Scoria	Sand	288	519	443	150	0.52	5	
6	ScPu 1	08/01/02	Scoria	Pumice	313	460	377	150	0.48	0	
7	ScPu 2	10/01/02	Scoria	Pumice	313	335	502	150	0.48	0	
8	ScSa - 60%	17/04/02	Scoria	Sand	313	347	520	150	0.48	3	
9	ScSa - 70%	18/04/02	Scoria	Sand	313	260	607	150	0.48	3	
10	ScSa - 80%	25/04/02	Scoria	Sand	313	173	694	150	0.48	5	
11	ScP - 70%	30/04/02	Scoria	Pumice	313	251	586	150	0.48	2	
12	ScP - 80%	01/05/02	Scoria	Pumice	313	167	670	150	0.48	3	

Table 3: Mix design for hollow concrete blocks with three cells

No	Mix Type	Date of Mixing	Course Aggregate	Fine Aggregate	Mix proportion in kg/m^3 of concrete				W/C ratio	Slump (mm)	Remark
					Cement	Coarse Agg.	Fine Agg.	Water			
1	PP 1	19/02/02	Pumice	Pumice	288	509	433	150	0.52	0	
2	PP 2	21/02/02	Pumice	Pumice	313	504	413	150	0.48	4	
3	Psa	26/02/02	Pumice	Sand	288	528	324	150	0.52	5	
4	ScSc	27/02/02	Scoria	Scoria	313	477	390	150	0.48	6	
5	ScSa 1	04/03/02	Scoria	Sand	288	519	443	150	0.52	0	
6	ScPu 1	07/03/02	Scoria	Pumice	313	460	377	150	0.48	11	
7	ScPu 2	11/03/02	Scoria	Pumice	313	335	502	150	0.48	0	
8	ScSa - 60%	22/03/02	Scoria	Sand	313	347	520	150	0.48	4	
9	ScSa - 70%	26/03/02	Scoria	Sand	313	260	607	150	0.48	4	
10	ScSa - 80%	29/03/02	Scoria	Sand	313	173	694	150	0.48	6	
11	ScP - 70%	03/04/02	Scoria	Pumice	313	251	586	150	0.48	2	
12	ScP - 80%	04/04/02	Scoria	Pumice	313	167	670	150	0.48	4	

STRENGTH TEST RESULTS OF HOLLOW CONCRETE BEAM TILES

General

Flexural strength tests were conducted at the age of 28 days for two types of loading; point load at mid span and uniform load. Point load applied at mid span of the hollow concrete blocks was intended to simulate construction loads such as workers stepping on it prior to casting of the slab, where as the uniform loading reflects the dead weight of fresh concrete after the slab is cast. Fig. 2 shows the experimental set up and a representative test specimen that has reached its ultimate flexural strength under uniform load.

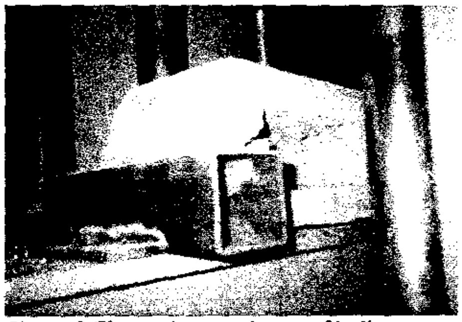


Figure 2 Flexural strength test of hollow concrete blocks

It was observed in the experiment that the hollow concrete blocks displayed significant strength reserves after first crack formation for the uniform loading condition. For point loading case however, the blocks collapsed immediately after the first cracks were formed. The test results for both types of hollow concrete blocks are shown in Tables 2, 4 and 5.

Table 4: Strength test results at the age of 28 days for two celled HCB tiles

No.	Mix Type	Date of Testing	Avg. weight of Cube (kg)	Avg. weight of HCB (kg)	Avg. Cube Crushing Strength (MPa)	Flexural strength of HCB			Remark
						Uniform Loading		Point Loading	
						Load at First Crack (kN)	Failure Load (kN)	Failure Load (kN)	
1	PP1	17/01/02		-------	4.48	------	25.55	-------	
2	PP2	18/01/02		12.26	5.75	3.5	25.23	4.3	
3	PSa1	22/01/02		11.76	5.08	4.77	27.03	3.5	
4	ScSc	31/01/02		17.93	8.61	5.43	42.53	5.53	
5	ScSa 1	01/02/02		17.87	8.92	7.27	55.53	6.53	
6	ScP1	05/02/02		15.72	11.42	5.6	49.03	4.86	
7	ScP2	07/02/02		13.68	7.99	4.47	47.93	3.93	
8	ScSa - 60%	15/05/02	5.88	17.78	16.6	6.8	53.43	5.1	
9	ScSa - 70%	16/05/02	5.80	16.13	13.92	7.0	34.27	3.6	
10	ScSa - 80%	23/05/02	5.85	14.99	8.85	3.2	24.8	3.3	
11	ScP - 70%	28/05/02	5.36	15.78	12.45	6.6	53.87	5.35	
12	ScP - 80%	29/05/02	4.88	12.82	8.75	3.37	32.6	2.67	

Table 5: Strength test results at the age of 28 days for three celled HCB tiles

No	Mix Type	Date of Testing	Avg. weight of Cube (kg)	Avg. weight of HCB (kg)	Avg. Cube Crushing Strength (MPa)	Avg. Flexural strength of HCB			Remark
						Uniform Loading		Point Loading	
						Load at First Crack (kN)	Failure Load (kN)	Failure Load (kN)	
1	PP1	19/03/02	4.41	10.52	6.46	4.27	34.1	3.57	
2	PP2	21/03/02	4.26	10.65	5.58	4.13	25.23	3.17	
3	PSa1	26/03/02	4.92	11.89	9.68	6.6	37.8	4.17	
4	ScSc	8/4/2002	6.33	17.73	15.03	6.6	38.43	5.93	
5	ScSa1	27/03/02	6.23	18.13	14.59	10.2	63.75	7.63	
6	ScP1	01/04/02	5.54	14.91	12.93	6.47	38.5	5.6	
7	ScP2	04/04/02	5.69	15.31	12.58	8.3	37	6.5	
8	ScSa - 60%	19/04/02	6.15	17.28	15.08	9.33	54.07	8.4	
9	ScSa - 70%	24/04/02	5.96	16.37	14.06	6.57	47.07	5.33	
10	ScSa - 80%	26/04/02	5.83	15.92	13.26	8.83	42.97	5.93	
11	ScP - 70%	01/05/02	5.64	15.08	13.3	6.67	45.57	6.8	
12	ScP - 80%	02/05/02	5.09	12.4	8.39	4.33	36.46	3.7	
13	Sc P - 60%	03/05/02	5.66	15.21	13.02	8.6	44.76	6.2	

Selection of Suitable Hollow Concrete Beam Tiles and Mix Type

Suitable mix proportions for the hollow concrete beam tiles were selected based on strength and weight considerations. Generally mix proportions with combinations of scoria with sand, and scoria with pumice seemed to posses the desirable quality with regard to strength, where as the two celled blocks were found to be lighter in weight. Therefore, a two-celled hollow concrete block with the mix type ScP 70% was selected and produced in large numbers for the construction of three experiment precast beam-slabs.

TEST RESULTS OF PRECAST BEAM ELEMENTS

General

The test program was intended to study the behavior of precast beam elements under loading that corresponds to the initial condition. The loading is gradually increased until the precast beam elements reach their ultimate capacity. The observations and measurements made during the experiments were intended to serve as benchmarks to test the theoretical results with regard to failure loads, failure modes, displacement calculations etc. Moreover, the experiments were designed to demonstrate whether this new type of construction responds in a ductile or brittle manner at load intensities close to the ultimate.

Control cubes were prepared and cured in water tanks at laboratory conditions. The 28 days strength test results are as shown in Table 6.

Table 6: 28 days test results of concrete cubes

No	Mass (gm)	Failure load (kN)	Compressive strength (MPa)
1	7960.0	1003.0	44.58
2	7965.4	1046.0	46.49
3	8023.8	1034.0	45.96
Average Compressive Strength = 45.6 MPa			

The precast beams were cured three times per day under shade for 14 days and tested for strength after 28 days. The test was conducted with a two point loading system on simple supports. Fig. 3 shows a photograph of the test setup.

Figure 3 Test Setup of the precast beam element on the bending testing machine

Three precast beams were tested and for each beam the mid-span deflection and failure load were recorded. The measurements were taken at intervals of load increment of 0.05 tons. The results of the experiment showed that the mode of failure for all three samples was due to buckling of the top member near the mid span. See a close up picture in Fig. 4. The results of the experiment do verify the analysis results in section 4 that the design of precast beam is governed by buckling at the initial stage.

Figure 4 Failure mode of the precast beam element

Comparison of Experimental and Analytical Results

System and Loading

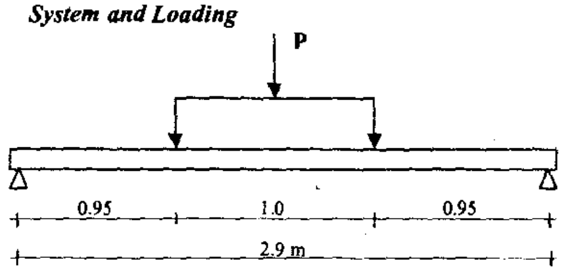


Figure 5 System and Loading of precast Beam

Loading

Own weight = 25*0.123*0.05 = 0.154 kN/m

Permanent load from loading setup = 0.277 kN

Load applied by the machine = P

In verifying the test results the space truss model shown in Fig. 6 is adopted. In analyzing the model the actual uniformly distributed load on the precast beam element is converted in to equivalent concentrated loads at the joints. The concentrated loads from the machine and the loading set up, on the other hand, are equally divided between the four nodes in the neighborhood of the point of application of the concentrated loads, which are located at 0.95 m from the supports as shown in Fig. 5. Experimental and theoretical load versus mid-span deflections are shown in Figs. 7, 8 and 9.

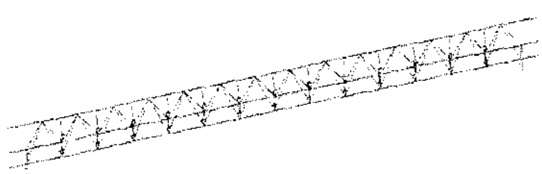


Figure 4-4 Space truss model of the precast element

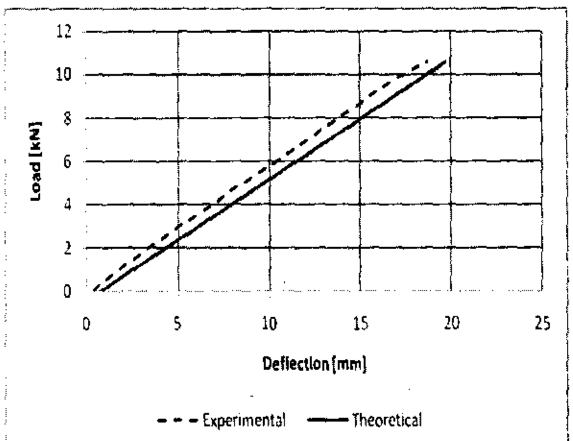


Figure 7 Load – Mid span deflection for specimen 1

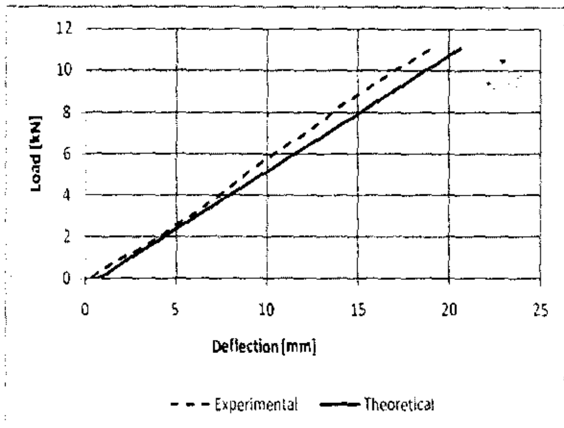


Figure 8 Load - Mid span Deflection for Specimen 2

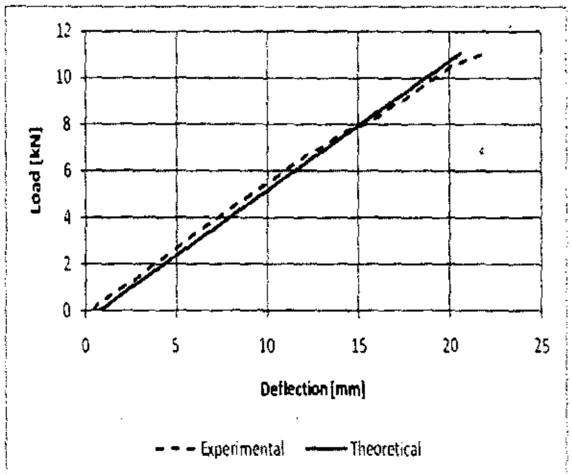


Figure 9 Load – Mid span Deflection for Specimen 3

Discussion of the test results

The mid span deflections from the experiment agree quite well with the prediction based on the space truss model. The theoretical load-deflection curve is linear showing that neither the critical tension nor critical compression members has yielded before reaching the ultimate state which is caused by buckling of the top reinforcements. The experimental load-deflection curves are also nearly linear with approximately the same slope as the truss models all the way from the beginning of load up to the ultimate.

The load-mid span deflections based on the theoretical results lie to the right of the experimental curves in Figs. 7, and 8 and most part of Fig. 9. This is as a result of tension stiffening of concrete between the cracks.

TEST RESULTS AND THEORETICAL STRENGTH DETERMINATIONS OF PRECAST BEAM-SLABS

General

Full-size beam-slabs spanning 3.0 m were constructed using the precast beam elements studied in the previous chapters to investigate their strength and deformation characteristics under service and ultimate loads. Two types of precast beam-slabs were tested. They were beam-slabs with and without topping. The predicted ultimate loads of the slabs are calculated using the idealized parabolic-rectangular stress block for concrete and elastic-perfectly plastic relationship for reinforcement.

The theoretical yield moment capacities of the cross sections were chosen in lieu of the ultimate capacities for strength comparison purposes because of the physical limitations with regard to deflection measurements after yielding of the reinforcement.

The mean compressive strength of the control cubes at the age of 28 days and the mean yield strength of the reinforcing bars were found to be 11 MPa and 465 MPa respectively. The test results for the compressive strength of concrete were rather low. However, the investigation was continued to avoid recasting of a full size slab. Besides this will not have bearing on the relative strengths found from analysis and experiment as long as the strength calculations are based on the observed mean compressive strengths.

Experiments on actual size beam-slabs

As mentioned in the previous section, two types of precast beam-slabs, namely beam-slabs with and without topping were constructed and loaded until the reinforcements started yielding. The specimens and test set up are as shown in Fig. 10 to 14. The aim of the experiment was to study the strength and deformation characteristics of the two types of beam-slab systems. For this purpose three slabs were constructed, Beam-Slabs I and II are with topping and Beam-Slab III is without topping. For the Beam-slabs with topping temperature reinforcement was provided.

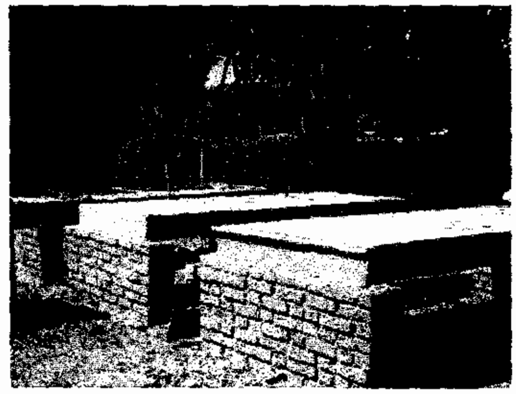


Figure 10 Precast beam-slabs with topping

Figure 11 Slab without topping- experiment set up with gauges

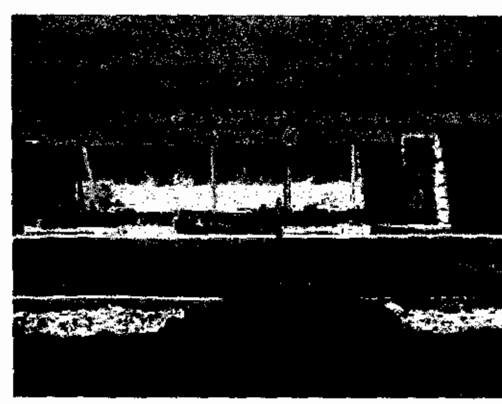


Figure 12 Slab with topping-experimental setup

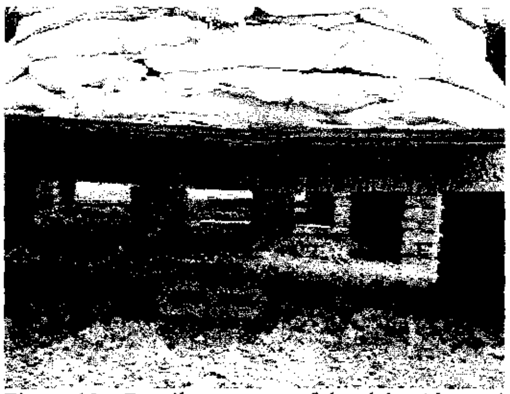


Figure 13 Ductile response of the slab with topping with gauges under load

Figure 14 Slab without topping at yield

The uniformly distributed load (sacks filled with sand) was applied over the middle portion of the slab to avoid dispersion of load directly to the supporting brick piers. The loading was gradually increased until the reinforcement had started yielding. This stage of loading was characterized by rapid increase in deflection at which time the dial gauges were removed and the load increment was almost simultaneously stopped. Mid-span deflection measurements were taken after each incremental loading and load versus mid span deflection curves shown in Figs. 15, 16 and 17.

For the precast beam-slab without topping a clear indication of yielding in terms of sudden heavy cracks was observed at a load of 24.2 kN. However, for the beam-slabs with topping such indication was not observed as such, but rather an increment in the deflection rate was observed. The yielding loads plus self weight for beam-slabs I, and II are 105.9 kN and 103.9 kN respectively. Deflection readings corresponding to further increase in loading were recorded as long as the physical limitations of approximately maximum dial readings allowed.

The formation of the sudden heavy cracks at the same time that the reinforcement is yielding is not paralleled in beam-slabs with topping. This may be attributed to the presence of a layer of reinforcement which lies in the tension zone, but has not yet reached the yield point and therefore inhibits the mobilization of the full yielding of the bottom reinforcement until it starts yielding itself.

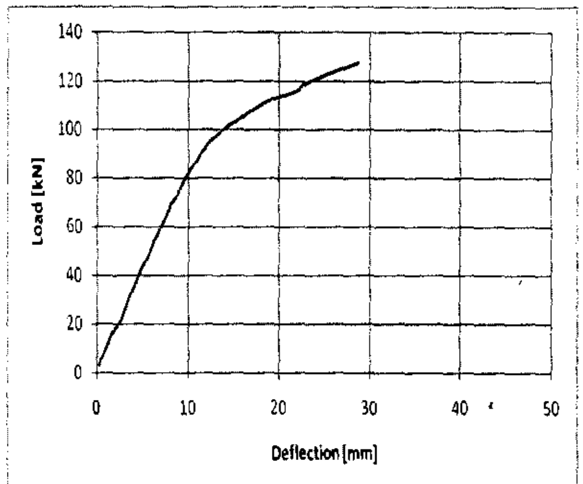


Figure 15 Load versus Mid-Span Deflection of Beam-Slab I

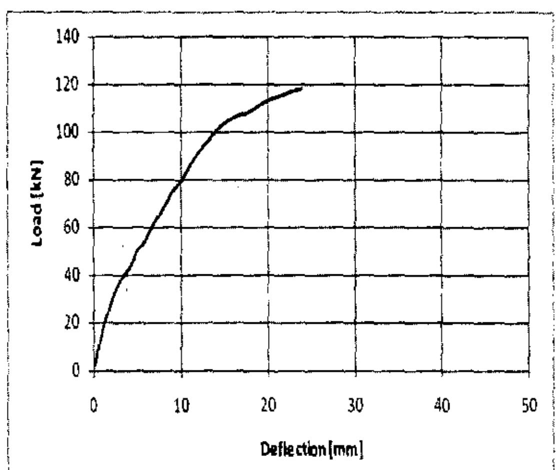


Figure 16 Load versus Mid-Span Deflection of Beam-Slab II

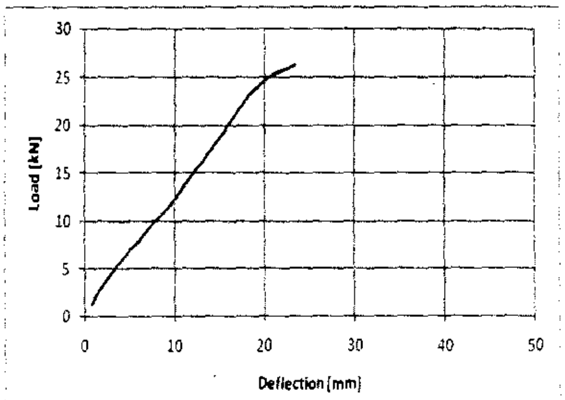


Figure 17 Load versus Mid-Span Deflection of Beam-Slab III

Comparison of test and analytical results

In the following the internal yield moments for the interior and edge beams of the test beam-slab subjected to loading that corresponds to the onset of yielding of the reinforcement will be determined.

Comparison of the results and discussion

Comparisons of moment capacities of the beams at yield from experimental and analytical results are shown in Table 7. In all cases the experimental yield moment capacities are greater than those found analytically. On the other hand the values compare quite well and thus justify the basic assumptions used in the derivation of the yield moment capacities for both types of slabs. References [2] and [3] are used for the analysis of the experimental precast beam element and slab section. Details of the cross-section analysis based on the Ethiopian codes are available in Reference [4].

Table 7: Theoretical versus Experimental Yield Moment Capacities

Type of slab	Yield Moment Capacities			
	Theoretical Results		Experimental Results	
	Exterior beam	Interior beam	Exterior beam	Interior beam
Beam-Slab I (with topping)	12.07	13.31	16.78	17.42
Beam-Slab II (with topping)	12.07	13.31	17	17.71
Beam-Slab III (without topping)	8.04	8.01	10.11	12.74

CONCLUSIONS AND RECOMMENDATIONS

i) The results of the experiments have verified that the ultimate capacity of precast beam-slabs is governed by buckling of the top reinforcement at the construction phase.

ii) The span length of 3.0 m for the precast beam under investigation satisfies the serviceability requirements for deflection. These may not be fulfilled for longer spans in which case intermediate supports may be required.

iii) The hollow concrete beam tiles bridge the space between the precast beam elements and are as such load bearing elements. Therefore they must satisfy the minimum strength requirement to be able to carry their own weight plus the weight of fresh concrete, which is directly deposited on them. Moreover they have to withstand the additional load due to workers stepping on them.

iv) Mix proportions with combinations of scoria with sand, and scoria with pumice seemed to posses the desirable quality with regard to strength, where as the two celled blocks were found to be lighter in weight. Therefore a two-celled hollow concrete block with the mix type ScP 70% was selected.

v) The experimental results showed that two celled hollow concrete blocks with mix type ScP70% could sustain a uniformly distributed load of 6.6 kN and a concentrated load of 5.36 kN before the formation of the first crack.

vi) The response under load of the two types of slabs (i.e. slabs with and without topping) is ductile making them suitable replacements for the regular type of reinforced concrete slab construction.

vii) Basic mechanics of reinforced concrete can be used for design and analysis of precast beams and/or precast beam-slab systems.

viii) Strength degradation (almost instantaneous formation of heavy cracks at the onset of yielding of bottom reinforcement) is more series for beam-slabs without topping. This may be improved by providing additional tension reinforcement close to the neutral axis.

ix) This type of construction is suitable for the desired purpose of reducing the consumption of timber formwork and with it the cost of construction.

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