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Behavior of Stepped Reinforced Concrete Beam Under Static Loads

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***Abstract* — This paper presents an investigation to study the behavior of stepped reinforced concrete beams under static load. An experimental study is carried out to test one stepped reinforced concrete beam. To verify the nonlinear finite element modeling constructed by the use of the nonlinear finite element program ANSYS in the analysis of the stepped reinforced concrete beam, one model identical to the experimentally tested beam is prepared and constructed by the use of this program. Analytical study is performed using the ANSYS finite element program to predict the ultimate load capacity. Nonlinear material behavior, as it relates to steel reinforcing bar and concrete are simulated appropriate constitutive models. The crack patterns of the beams are presented. The load deflection plots are obtained. The analytical results show good agreement with the experimental results.**

Keywords— Stepped beam; Experimental study; Analytical study; Verification; Ansys.

I. INTRODUCTION

Non prismatic beams have been used in various structures including buildings and bridges since the first decades of the previous century, with an increasing application as the structural engineering techniques were improved. With the beams being tapered, the architects would be able to create and implement novel aesthetic architectural designations, as well as the structural engineers who could seek for optimum low weight - high strength systems through a redistribution of materials along the structural members [1]. Experimental based testing has been widely used as a means to analyze individual elements and the effects of concrete strength under loading. While this is a method that produces real life response, it is extremely time consuming and the use of materials can be quite costly. The use of finite element analysis to study these elements has also been used. In recent years, however, the use of finite element analysis has increased due to progressing knowledge and capabilities of computer software and hardware. It has now become the choice method to analyze concrete structural components. The use of computer software to model these elements is much faster, and extremely cost-effective. The use of FEA has been the preferred method to study the behavior of concrete (for economic reasons) [2]. Chetankumar *et al* presented an analytical analysis for the deflection of trapezoidal sectorial section with uniformly perpendicular loading condition. The method illustrated was comparatively easy and can be applied for the similar other sections as well. Analytical method is validated using finite element analysis [3]. Finite element programs are used to study the behavior of reinforced concrete beams strengthened by fiber reinforced polymer. These numerical studies could be used to predict the behavior of retrofitted reinforced concrete beams more precisely by assigning appropriate material properties [4-10]. Saifullah *et al* presented an investigation to evaluate the use of finite element method for the analysis of reinforced concrete beams. An analytical investigation was carried out for a beam with ANSYS, SAS 2005 with different reinforcement ratio (under, balanced, over). The results demonstrated that from the analytical investigation it was observed that under reinforced ratio is the best type of reinforcement ratio among the others since it shows greatest warning zone before failure. Where warning zone for balanced condition and over reinforcement ratios were 81.52% and 28.77% of under reinforcement condition respectively [11].

This paper presents an experimental and analytical study to investigate the behavior of stepped reinforced concrete beams.

II. EXPERIMENTAL STUDY

A. Test Specimen

The tested beam had a rectangular cross section with a height of 150mm (sec. A)and 225mm (sec. B), a width of 100mm, and a length of 2000mm, (as shown in fig. 1). Two bars of 10mm in diameter provided main longitudinal reinforcement. Two other bars placed at top of the beams, each of 8mm in diameter, served as stirrups hangers for (sec A) and two bars of 10mm in diameter provided main longitudinal reinforcement. Two other bars placed at top of the beams, each of 10mm in diameter for (sec B). Stirrups formed from 6mm diameter steel bars, which spaced at 100mm, provided shear reinforcement. The average concrete compressive strength after 28 days equals to 38 N/mm2. Deflections of tested beam were measured at mid-span. Values of deflections were recorded for each beam at different stage of loading.

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B. Material properties

The concrete used was normal strength concrete of 38 MPa compressive strength, which was the average of six standard cubes of 150 *150*150 mm side lengths that were tested at the same time of testing the beam. The concrete mix contained Dolomite with nominal maximum size of 20 mm was used as coarse aggregate, Natural siliceous sand free from impurities was used in test specimens as fine aggregate. Ordinary Portland cement with grade 42.5 N was used with 350 Kg/m3. Water-cement ratio kept as 0.55. The longitudinal steel bars were high tensile steel of 500.3 MPa as the yield strength, while the maximum tensile strength was 826 MPa. The transverse steel was mild steel of 263 MPa yield strength and 369 MPa maximum tensile strength.

C. Test Setup, Test Procedure and Instrumentation

The available hydraulic machine was used, which controlled the concrete dimensions of the tested beams. The beams were rested on roller supports. The applied load by the testing machine was transmitted to the tested beams through a spreader beam (I-beam) supported on two cylinder bars giving two loading points. The distance between the two loading points was taken 600 mm for beams with span 1800 mm. At the beginning of testing, the beam was adjusted on the testing machine with the proper clear span, and then the load was applied by using the spreader on the tested beam under the testing machine. Deflection was measured at the mid span of the beams and under concentrated loads by using linear vertical displacement transducers (LVDT), and the formation and propagation of cracks was observed by necked eyes, where each of the test specimens was painted by a white color to facilitate the observation of cracks as shown in fig. 2.

D. Results and discussion of experimental tested beam

At the experimental tested beam the first crack began to appear at 7KN and with deflection equal to 4.8mm. The first crack appeared as diagonal crack at the lower part of the step. As applied load increased diagonal cracks appeared all over the step from lower to upper. The width of the cracks increased specially at the separated part between the upper and the lower part of the step. The beam failed due to decreasing in stiffness at 15 KN and at deflection 18mm.as shown in fig. 3. As shown in fig.4 which demonstrated that at the first time from initial loading up to 13 KN the beam exhibited linear behavior, where the beam started to crack at 7KN. from 13 KN until failure happened at 15 KN the beam exhibited nonlinear behavior.

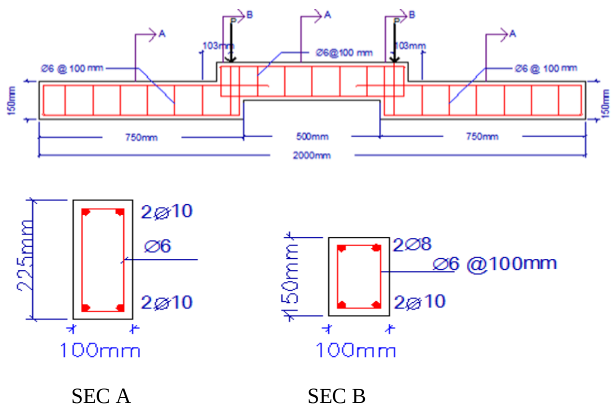

Fig. 1. Experimental tested beam dimensions and reinforced details

Fig. 2. Test setup for experimental tested beam

Fig. 3. Crack paatern of experimental tested beam

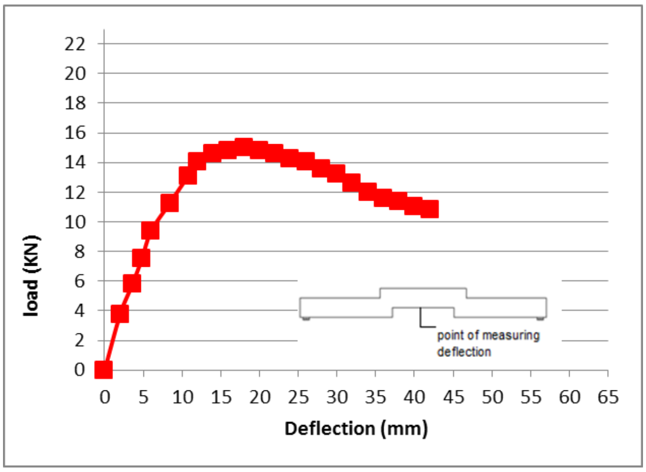

Fig. 4. Load deflection of experimental tested beam.

III. ANALYTICAL STUDY

The finite element method is considered as a very effective technique for solving different types of continuum problems under static or dynamic loads. In the finite element analysis, the continuum problem, which has infinite degree, is modeled to one which finite number. The problem is divided to a mesh of finite size elements connected to each other by nodes. Each element has finite number of independent degrees of freedom at its nodes. Too many finite elements are derived one; two and three dimensions problems can be solved using the finite element method such as, plates, shell, and plain stress, and plain strain, axi– symmetric and solid elements. ANSYS is a finite element analysis tool for structural analysis including linear and nonlinear and dynamic studies. This computer simulation program provides finite elements to model behavior, and supports material models and equation solvers for a wide range of design problems. To verify the nonlinear finite element modeling constructed by the use of the nonlinear finite element program ANSYS in the analysis of the stepped reinforced concrete beam, one model identical to the experimentally tested beam is prepared and constructed by the use of this of this program.

A. Finite element modeling

ANSYS element library contains more than 150 different element types. Each element type has a unique number and a prefix that identifies the element category, ANSYS 2011, [12].

SOLID65 provides the opportunity to model reinforced concrete. SOLID65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined [12].

The concrete element is similar to a 3-D structural solid but with the addition of special cracking and crushing capabilities. The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar are assumed to be "smeared" throughout the element. In case of concrete, real constants defined only for SOLID65 element. A sweep command was used to mesh all volumes and all meshes are rectangular. The element type number, material number, real constant set number, and element coordinate were set for each mesh for reinforced concrete. Maximum meshing dimension is 25 x 25 mm as shown in fig. 5. To ensure that the model acts the same way as the experimental beam boundary conditions need to be applied at points of symmetry, and where the supports and loading exist. The support was modeled as a hinged support at end and roller support at the other end one.

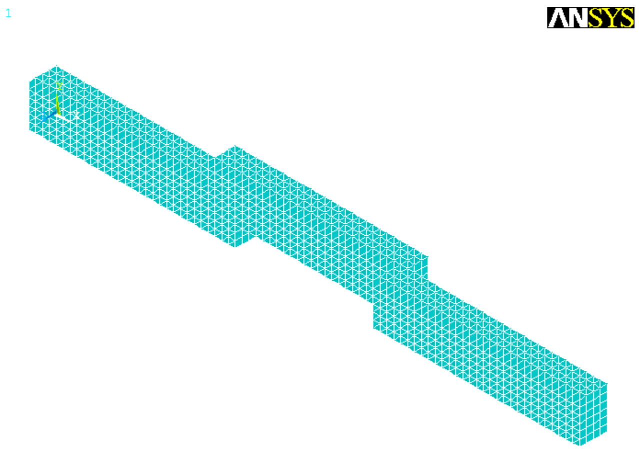

Fig. 5. Meshing of Stepped reinforced concrete beam

B. Material properties

TABLE I. MATERIAL PROPERTIES FOR ANALYTICAL TESTED BEAM

Element Type	Material NO.	Properties			Category
SOLID65	Material Model NO. *25	Linear properties	Linear Isotropic		Concrete
			EX	26673	
			PRXY	0.2	
		Nonlinear properties	Multilinear Isotropic		
			Strain	Stress	
			0	0	
			0.00026	6.9349	
			0.00054	13.651	
			0.00095	21.024	
			0.0015	26.038	
			0.0022	30.4	
			0.03	30.4	
			Concrete		
			Temperature	0	
			Open shear transfer coefficient.	0.5	
			Closed shear transfer coefficient	1	
			Uniaxial Cracking Stress	3.8	
			Uniaxial Crushing Stress	38	
			Biaxial Crushing Stress	**	
			Hydrostatic Pressure	**	
			Hydro Biax. Crushing Stress	**	
			Hydro Uniax. Crushing Stress	**	
			Tensile Crack Factor	**	
	Material Model NO. *240	Linear properties	Linear Isotropic		Transverse steel bar
			EX	$2*10^5$	
			PRXY	0.3	
		Nonlinear properties	Bilinear Isotropic		
			Yield stress	263	
			Tang Mod	0	
	Material Model NO. *360	Linear properties	EX	$2*10^5$	Longitudinal steel bar
			PRXY	0.3	
		Nonlinear properties	Bilinear Isotropic		
			Yield stress	500.3	
			Tang Mod	0	

* Labeled number. ** Default input data

C. Results and discussion of Verification model

The analytical results for the verification model were presented and compared with experimental values. Fig. 6 shows the cracks pattern of the verification model and the experimental tested beam. At the analytical tested beam, the first cracks are shown with a red circle outline, the second crack with a green circle outline, and the third crack with a blue. .Fig. 7 contains a comparison between the load-deflection curves predicted by ANSYS and the experimental result. Table II shows comparison between the verification model and the experimental tested beam.

Fig. 6. crack patterns of the verification model and the experimental tested beam

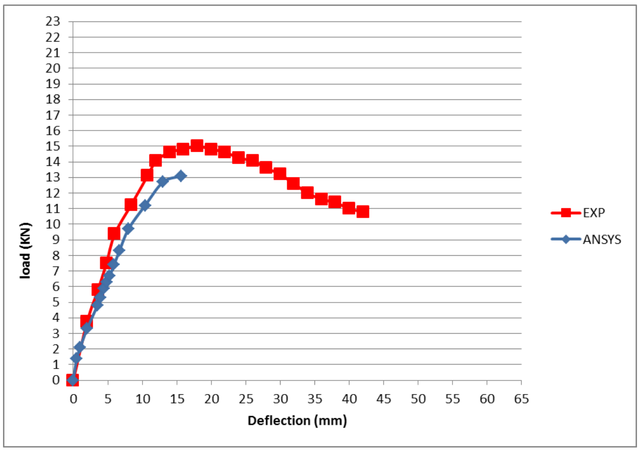

Fig. 7. load-deflection of the verification model and the experimental tested beam

TABLE II. Comparison Between the Verification Model and the Experimental Tested Beam

Beam	Experimental	Analytical	ANA./EXP.
Ultimate load (KN)	15	13.1	0.873
Deflection (mm)	18	15.6	0.866

IV. CONCLUSION

This paper presents an experimental and analytical investigation to study the behavior of stepped reinforced concrete beams. Based on results obtained from the investigation, the following can be concluded:

1 The agreement between experimental results and analytical simulation is very good.

2 The cracks of the tested beams were concerned in the stepped portion.

3 The difference percentage between the experimental and analytical tested beams is 12.6% for ultimate load and 13.3% for deflection.

4 The present nonlinear finite element model is a powerful tool and it can provide the researchers with a lot of important information that cannot be supplied by the experimental test.

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