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A study on the impact behavior unbonded post tensioned concrete beams under drop weight impact using non linear finite element modeling methods

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ABSTRACT

This paper presents the analysis from the simulation of unbonded post tensioned concrete beams under drop weight impact. Four beams were simulated using nonlinear finite element dynamic analysis (NLFEDA) software by impacting a mass of 420 kg at a velocity of 2.5 m/s onto the midspan of simply supported beam members. Variables for the concrete beams were the level of post tensioning forces which were equal to 50, 100, 150, and 200 kN per tendon. Beams were designed to fail under flexure under static conditions per ACI (2014) guidelines. Analysis was done pertaining to the impacting loads at the midpoint (three point bending configuration), the observed reaction forces at the supports, and member deformation.

1. INTRODUCTION

The understanding of structures under impact conditions is of highly relevance. Impacting loads and can be caused due to the presence of projectiles or natural disasters. Under normal conditions, these loadings can include debris onto projective rock sheds and impact onto piers due to automobiles. While design precautions have been taken into account for the design of these structures against impacting loads, structural failure due to impact is a well-documented occurrence. As member failure under large dynamic forces is relatively instantaneous, there exist many complexities attributed to member instrumentation and data collection (when large scale testing is being considered). This leads to a robust level of complexity when designing the testing set up and appropriate instrumentation. A common method of laboratory testing for concrete beam members is the use of a drop weight testing apparatus. As the name implies, this method of test is based on a falling weight dropped onto the midspan of a simply supported beam (three-point bending configuration). The input variables of this testing set up rely only on the mass of the drop weight and the height at which it was

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dropped. However, these tests can be expensive. Negating these costs, the use of properly validated nonlinear finite element dynamic analysis (NLFEDA) modeling has become suitable for mimicking these testing set-ups.

Due to the ease of use, commercial software has proven to be the popular choice when performing simulations. Validation of the model is general tuned to the sensitivity of the model to the geometric mesh size and properties of the materials used. For the modeling of large scale of concrete members, two typical range of mesh sizes have been used. A relatively more coarse mesh in the range of 20 to 25 mm has been used with finer meshes measuring at around 10 mm. It was noted that anything smaller than 5 mm is only added to the computational time and no large benefits at model accuracy. For this present study, four unbonded post tensioned (PT-RC) beams were modeled under impacting loads using NLFEDA methods. There are both few laboratory and numerical studies in regard to PT-RC members, and the current investigation was done to look at the fundamental concepts of drop weight testing onto PT-RC members.

2. RESEARCH METHODS

Four unbonded PT-RC beams were simulated under impact with a 420 kg mass at an impact velocity of 2.5 m/s. The members included both conventional bonded and unbonded reinforcement. Both the top and bottom longitudinal reinforcement was comprised of 20 mm diameter rebars. For the transverse reinforcement, 10 mm stirrups were used. Unbonded PT reinforcement was supplied by a 25 mm bar placed at a depth of 260 mm from the top compressive fiber. The design cross section is provided in Fig. 1. The stirrups contained within the critical area were spaced at a distance of 100 mm on center. Variables for this study were the level of PT force applied to the beam. The four levels of PT were equal to 50, 100, 150, and 200 kN. Concrete strength for this study was specified to be 20 MPa. Strengths of all steel reinforcement can be seen in Table 1.

Table 1 Material properties

Concrete	Steel Reinforcement					
	ϕ10 (transverse)		ϕ20 (longitudinal)		ϕ25 (PT bar)	
f'_c	f_{ty}	f_{tu}	f_y	f_u	f_{py}	f_{pu}
20	656	735	464	597	973	1128

The resulting design strengths from these members are given in Table 2. The static flexural and shear capacities (ACI 2014) were in the range of 224 to 307 kN and 923 to 1049 kN, respectively. The shear to flexural capacity was well above 1.0 in all cases, thereby signifying an expected flexural failure in the case of static testing. When undergoing impacting loads, such as from drop weight testing, an expected case of mixed shear and flexural cracking is anticipated. The notation for the specimen ID is given by “F”, representing flexural-critical type; then followed by “S100”, noting a shear spacing of 100 mm; and lastly the designation “PT”, followed by a numerical value, representing the value of the effective PT force applied.

Table 2 Specimen properties

ID	P_u (kN)	V_u (kN)	Capacity Ratio (V_u/P_u)
F.S100.PT50	224	923	4.11
F.S100.PT100	254	965	3.78
F.S100.PT150	282	1007	3.56
F.S100.PT200	307	1049	3.41

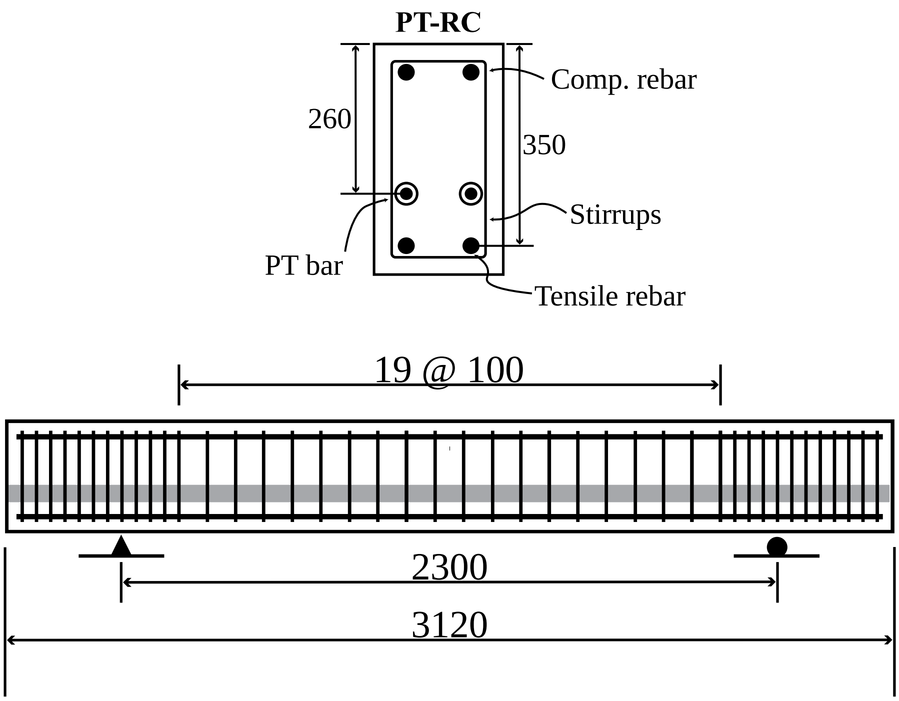

Fig. 1 Specimen design

Modeling was done using the LS-Dyna software. The following material models were used for the steel and concrete, "003 Plastic Kinematic" and "159 CSCM", respectively. Steel stirrups and rebars were embedded in the concrete material using the "Lagrange in Solid" keyword. In order to avoid deformation in the testing set-up, a rigid material was used for defining both the support system and hammer drop weight. Mesh size for solid elements was equal to 10 mm. Beam elements used for steel reinforcement were equal to 10 mm. View of the model is shown below. Results of the modeling are provided in the following section. A view of the model is given in Fig. 2.

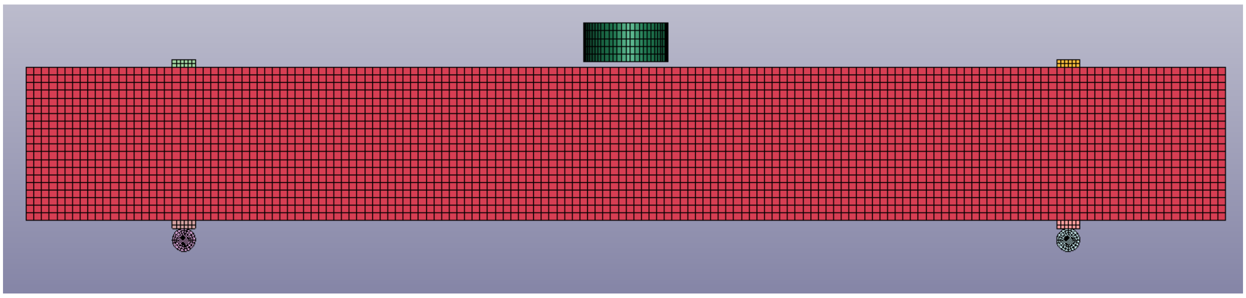

Fig. 2 Modeling of drop weight testing in LS-Dyna

3. FINDINGS

The observed plastic strain post impact is provided for F.S100PT50 and F.S100.PT200 in Fig. 3. These cases represent the typical case as observed throughout all models during the investigation. A definite shear plug is shown originating at the impact point at the midspan. For F.S100.PT50, some shear cracking can be seen near the support points at the left. This type of failure is typical for concrete members when subjected to impact, even for flexural-critical members.

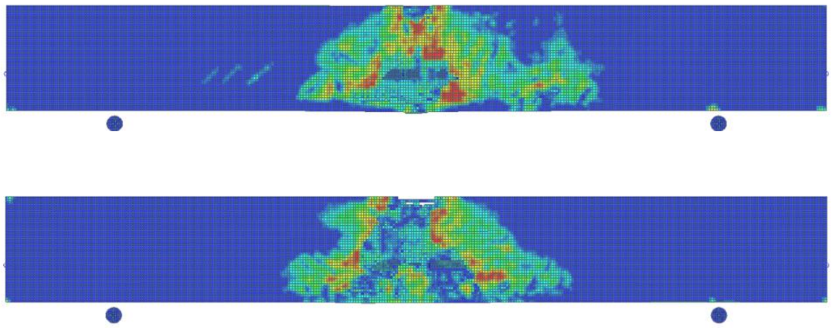

Fig. 3 Plastic strain of F.S100.PT50 (Top) and F.S100.PT200 (Bottom)

The time history of the force at the impact point (hammer), summation of the reaction forces and PT bar are shown in Fig 4. Displacements are also provided along the right portion of the figure. The qualitative behavior for all cases is similar. For the force at the hammer or impact point, a short duration high amplitude load occurs. This was approximately 1,500 kN for all cases. The peak measured reaction forces were equal to 374, 435, 594, and 548 kN for PT levels of 50, 100, 150, and 200 kN, respectively. The increase in capacity over the calculated static was about 1.5. This behavior is in agreement with that as observed from other laboratory studies. Peak displacements were in the range of 5 to 7 mm. All cases show some increase in the PT force at impact.

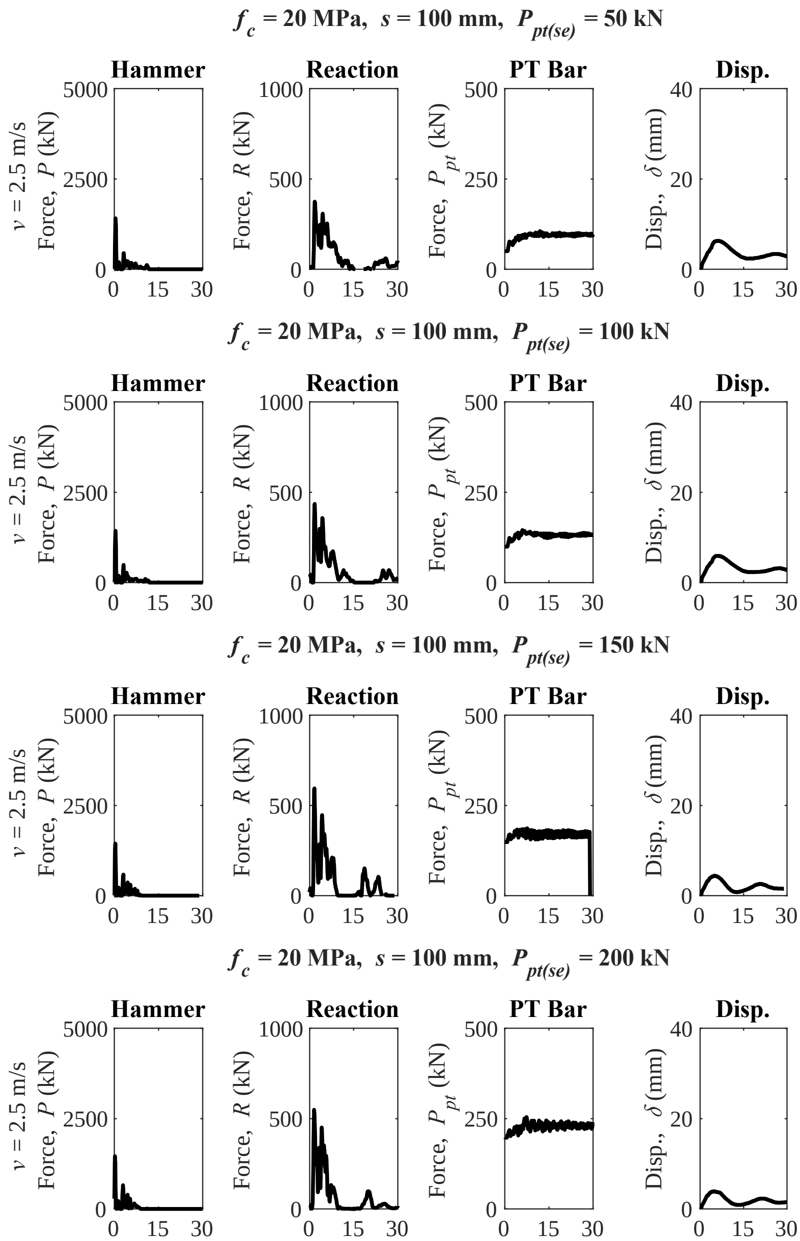

Fig. 4 Time history of results

REFERENCES

ACI Committee 318 (2014), *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)*, American Concrete Institute, Farmington Hills, MI.