Responsible Design and Delivery of the Constructed Project
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THE EFFECT OF IMPACT LOADS ON PRESTRESSED CONCRETE SLABS

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Many research studies have been conducted on the effect of impact loading on structures, and design procedures were proposed for reinforced concrete (RC) slabs; however the availability of these studies and procedures are limited for prestressed slabs. The proposed research will examine, using numerical analysis, the impact of rock fall on prestressed concrete slabs with equivalent moment capacity reinforced concrete slabs. It is expected that prestressed concrete slabs will have different behavior to resist impact loading compared with traditional reinforced concrete slabs. The thickness of the prestressed concrete slab will be 25cm whereas that of the reinforced concrete slab will be 30cm. The impact loading consists of 500Kg drop weight. The drop height will be 10m, 15m and 20m.The structural analysis is performed using a Finite Element program "ABAQUS". A comparison will be done between both slab types in terms of failure mode, damage, and deflection. It has been found that both slabs failed in punching. However, the RC slab performed better than the prestressed concrete slab with respect to the value of the deflection at mid-span, while both showed punching shear mode of failure.

Keywords: Prestressing, Punching, Deflection, Capacity, Drop weight, Dynamic behavior.

1 INTRODUCTION

Prestressed concrete slabs are widely used in various floor types such as residential, industrial, and commercial buildings as well as in special constructions like bridges and complex structures. Usually, the floor system forms the major part of the cost of a building. The use of prestressed slabs reduces the cost of the construction and the time of execution. Also, in some special structural cases such as large spans, prestressed slabs are more economical and less complicated to implement. However, their resistance to impact damage caused by threats such as rock fall or other impact loads is currently under high interest.

The risk of rock fall accidents is increasing in habited mountain zones due to environmental changes, thawing of the forests, and manmade modifications on the natural landscape. Experts need to expand their knowledge and safety against rock fall threats especially with the growth of population and the high mobility, such as reported into and through Alpine areas by Schellenberg *et al.* (2016).

There is growing recognition of the importance for resistant structures and, in consequence, a need for tolerable, related evaluation and design processes. As to impact resistant structures, many studies have accounted an assessment of the behavior of reinforced concrete slabs under impact load such as Berthet-Rambaud *et al* (2002), Hrynyk and Vecchio (2014), and Sagals *et al*. (2015).

The majority of impact-related research has been concentrated on developing empirical formulae to estimate the element damage and capacity under precise types of impact-loading circumstances. However, the success in developing these formulae was limited. Moreover, with respect to prestressed slabs, much of the work has been exclusively focused on localized damage mechanisms such as concrete scabbing and missile penetration, (Thai and Kim 2017). Other aspects such as quantification of the damage in terms of width and depth of the scabbed area, or in terms of the failure mechanism, are rarely mentioned (Orbovic *et al* 2009).

2 NUMERICAL MODELING

2.1 Size and Geometry

Six numerical slab models have been studied using finite element software "ABAQUS". The aim is to evaluate the behavior of prestressed slabs compared to an equivalent in moment capacity reinforced concrete slab under impact load. This load is a falling weight from three different heights: 10m, 15m and 20m respectively as shown in Table 1. The drop weight consists of 500kg reinforced concrete block as shown in Figure 1. As for slabs' dimensions, prestressed slabs (PT Slabs) and reinforced concrete slabs (RC slabs) have the dimensions of 3m*6m with different thickness of 0.25m and 0.30m, respectively. Both slabs have longitudinal reinforcement of T16 at 150mm in both directions. The PT slabs have, also, 6 tendons made up of 2 strands (area of $99mm^2$ each). All slabs are simply supported in the long direction. The supports are steel plates resting on neoprene pads as shown in Figure 2.

2.2 Finite element Modeling

For modeling procedure in ABAQUS, concrete elements and supports were modeled using an eight-node linear brick element (C3D8R) as shown in Figure 3. Each node has three degrees of freedom, (Ellobody and Bailey 2009). Steel reinforcements and tendons were modeled as two-node linear 3-D truss elements. All steel reinforcement was assumed to be fully embedded inside the concrete body.

The "Concrete Plasticity Damage (CDP)" model (built-in ABAQUS model) was used to represent the concrete material stress-strain non-linear relationship. This model has high performance in dynamic and impact load analysis. The compressive strength considered in this study was 30 MPa. For steel reinforcement an elastic-perfectly plastic behavior was considered with yield strength equal to 420 MPa. On the other hand, steel tendons were defined using bi-linear behavior with yield strength of 1860 MPa.

Table 1. Study cases.

Drop Height(m)	Type of Slab	Model Name
10	PT	M1
	RC	M4
15	PT	M2
	RC	M5
20	PT	M3
	RC	M6

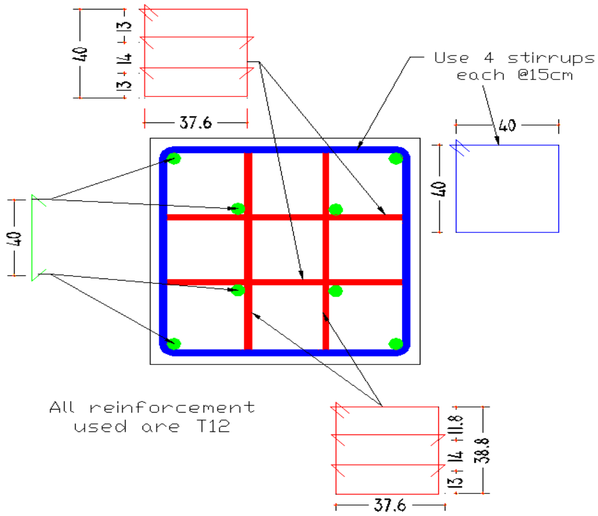

Figure 1. Drop weight reinforcement (cm).

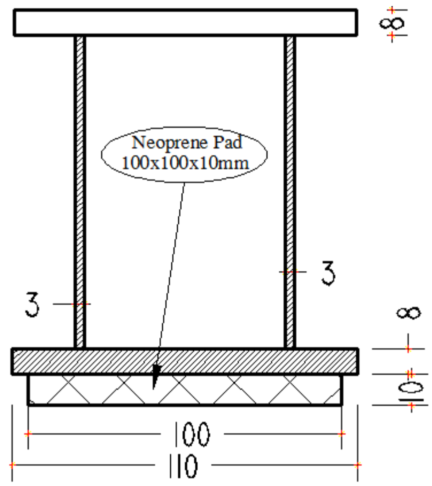

Figure 2. Steel cylinders (mm).

Regarding the prestressing force, a predefined field of type "initial stress" in the axial direction was defined, and a value of 1440 MPa was considered as a jacking stress. An initial speed was defined for the falling object equivalent to its real speed when reaching the top surface of slab. Block speed can be determined from Eq. (1), where "g" is the gravity acceleration and "h" is the height of falling object.

$$V = \sqrt{2gh} \tag{1}$$

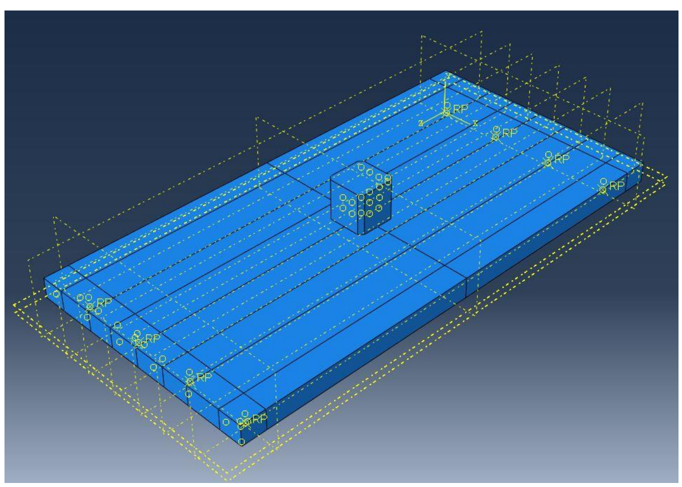

Figure 3. Finite element model.

2.3 Material properties under impact loads

Concrete behaves in a different way when subjected to impact loading. Its strength and stiffness under impact will be higher when subjected to static loading (Temsah *et al*. 2017). Many researches were conducted to study the tensile and compressive strength of concrete at different applied load rates. Some of the published results are presented in Malvar and Crawford (1998). As for reinforcing steel, the behavior is also affected when applying impact load. The yield strength will be increased as well as the ultimate strength, but the modulus of elasticity will not be affected. Figure 4 shows the stress strain curve of the concrete under different load rates.

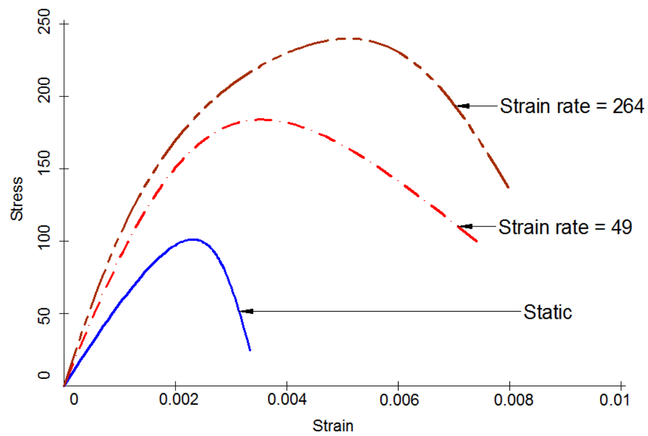

Figure 4. Concrete stress strain curve.

3 RESULTS AND DISSCUSION

3.1 Failure mode

The most critical impact effect was on the slabs subjected to drop weight from 20m. The governing mode of failure was punching shear failure as can be seen in Figures 5 and 6.

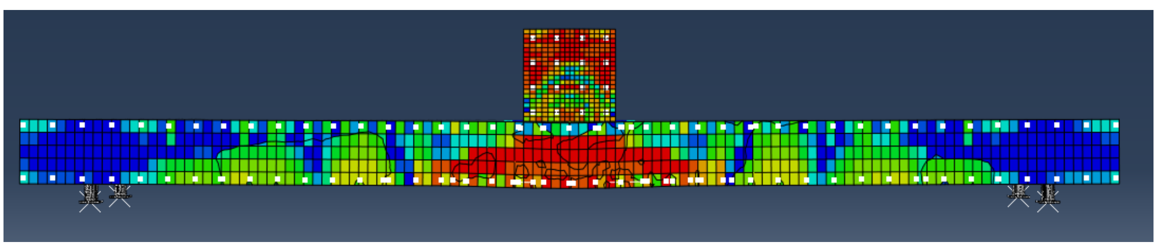

Figure 5. Punching failure in RC Slab due to 20 meters drop.

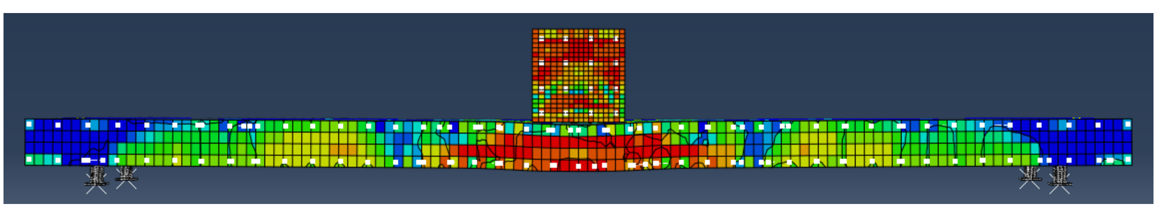

Figure 6. Punching failure in PT Slab due to 20 meters drop.

The punching shear mode of failure under impact load was shown through the experimental work of many researchers such as Orbovic *et al.* (2009), Hrynyk and Vecchio (2014), and Sagals *et al.* (2015). Then, the numerical analysis complies with the previous research studies as for the mode of failure.

The extent of the tensile damage zone was about 1.6m in PT slab and 1.5m in RC slab, whereas in the compression zone the damage was limited due to the top steel reinforcement used.

3.2 Mid-Span Deflection

The mid span deflection results are summarized in Table 2 and shown in Figure 7 for all slabs. The difference in deflection between the prestressed slab and reinforced concrete slab was about 10% when subjected to the impact load from both heights 10m and 15m. This percentage was dramatically raised to about 35% when the height was changed to 20m. It can be realized that the RC slab is better performing than the equivalent PT slab in terms of deflection in all cases. Again that can be justified by the inertia of the RC slab due to the increased thickness. This is different than what previous studies have shown since none of them compared PT slab to an equivalent moment capacity RC slab.

Table 2. Mid span deflection for all samples.

Drop Height(m)	Type of Slab	Model Name	Velocity at impact(m/s)	Energy at impact(KJ)	Mid-span Deflection (mm)
10	PT	M1	14	49	17.324
	RC	M4			15.678
15	PT	M2	17.5	73.5	23.639
	RC	M4			21.277
20	PT	M3	19.8	98	34.377
	RC	M6			26.111

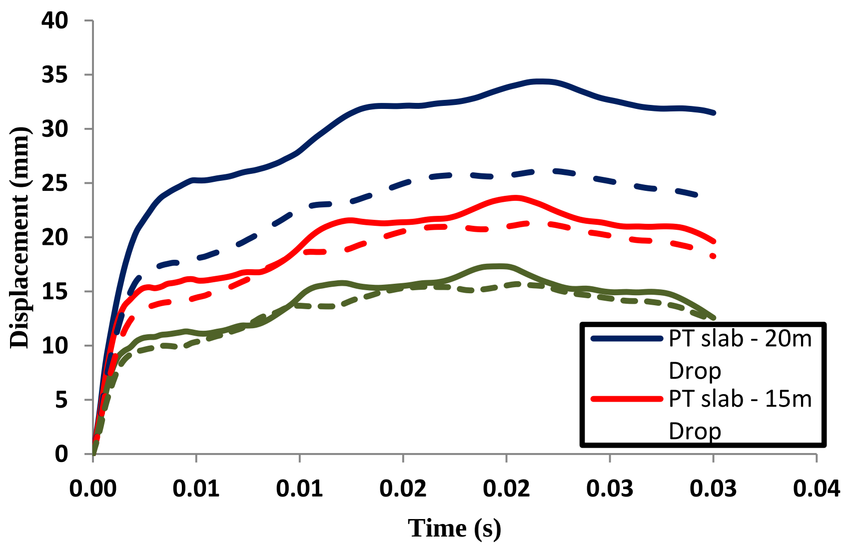

Figure 7. Deflection time history for all slabs.

4 CONCLUSION

The following conclusions can be drawn from the current investigation:

(i) The behavior of prestressed concrete slabs and its equivalent in moment capacity reinforced concrete slabs is different under impact of falling load.

(ii) The analysis showed that both types of slabs subjected to impact load due to drop weight are likely to fail due to local punching shear. Therefore, this mode of failure should be considered in any design procedure in the future.

(iii) The area of damage zone in prestressed concrete slabs was greater than those of reinforced concrete slabs, due to higher damage level of prestressed concrete slabs.

(iv) The inertia has a great effect on the behavior of slabs when subjected to impact loading, especially when the mode of failure is Punching shear failure. That was concluded from the difference in deflection between RC and PT slabs.

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